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FLOW DIAGONISTICS, CHEMICALLY REACTING TURBULENT FLOW MODELING AND TURBULENT MIXING

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130P

A SUMMARY OF PROJECT STUDIES IN COMBUSTION

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(NASA-CR-197348) FLOW DIAGNOSTICS, CHEMICALLY REACTING TURBULENT FLOW MODELING AND TURBULENT MIXING: A SUMMARY OF PROJECT STUDIES IN COMBUSTION (Cleveland State Univ.) 130 p

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PUBLICATIONS

EXPERIMENTAL

- o FLOW VISULIZATION
- o LDV

SIMULATIONS

- o STRAIGHT VS CURVED

KINETICS MODELING (NO_X)

- o TURBULENT MIXING MODEL FOR O_2
- o MAXIMUM MIXEDNESS MODEL

A NUMERICAL SIMULATION OF THE EFFECTS OF POSITION AND SPRAY OF THE FUEL INJECTION NOZZLE ON MIXING IN A CIRCULAR COMBUSTOR

Bahman Ghorashi and Sastry Taruvai
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Cleveland State University
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6th Miami International Symposium on Heat and Mass Transfer

Optimum Baffle

Baffle (Ht/Wth) = 0.83

Percent of Combustor

Diameter =35.5

NUMERICAL SIMULATION OF FLOW AND THE EFFECT OF BAFFLE ARRANGEMENT ON PRESSURE DROP AND TEMPERATURE PATTERN IN A CIRCULAR COMBUSTOR

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8th International Conference on Mathematical and Computational Modeling

CONCLUSIONS

- The optimum baffle size should be about 2.5 inches in height for a 3.0 inch base baffles

- The "out-of -phase" arrangement of baffles is more desirable than "in-phase" arrangement

FLOW VISUALIZATION AND COMPUTATIONAL STUDIES OF A REVERSE FLOW COMBUSTOR

B. Ghorashi, F. Reardon, G. McBeath
and
K. Chun
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32nd Heat Transfer and Fluid Mechanics Institute

CONCLUSIONS

- **The temperature distribution becomes relatively uniform as the fuel spread angle increases**

- **The overall effect of the injector position on mixing was not very apparent. Certain patterns were observed, nonetheless, additional optimization studies are needed**

PROCEEDINGS OF THE 32nd HEAT TRANSFER AND FLUID MECHANICS INSTITUTE

Held at
California State University, Sacramento
June 6 & 7, 1991

Edited by
Frederick H. Reardon
and
Ngo Dinh Thinh
Department of Mechanical Engineering

School of Engineering and Computer Science
California State University, Sacramento
Sacramento, California

CONCLUSIONS

- PATTERN DEPICTED BY SMOKE VISUALIZATION WAS DESIRABLE FOR RAPID MIXING OF FUEL AND AIR

- MORE EFFECTIVE ATOMIZATION OF FUEL IS REQUIRED

- LOW INJECTION VELOCITY AND LARGE SPRAY ANGLE PRODUCED A MORE UNIFORM TEMPERATURE DISTRIBUTION AT EXIT

FLOW VISUALIZATION AND COMPUTATIONAL STUDIES OF A REVERSE FLOW CIRCULAR COMBUSTOR

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ABSTRACT

Computational Fluid Mechanics Studies using the Fluent computer program and flow visualization studies were undertaken to support the development of a reverse-flow circular combustor design. The reverse-flow circular combustor combines a circular geometry with multiple fuel injection nozzles in Mini-Combustion Zones (MCZ). An overall combustor model was developed and used to determine the effects of fuel injector design on the temperature distribution throughout the combustor, with particular attention to the combustor exit. Low injection velocity and large injection spray angle were found to produce a more uniform temperature distribution at the exit.

The flow pattern depicted by the smoke visualization technique showed a behavior which is very desirable for the rapid mixing of fuel and air. The atomization of fuel was visualized by injection of a yellow dye smoke in the liquid side of the air-blast injector. The portion of the combustor volume that was investigated consisted of four baffles on the outermost circular surface and two baffles on the innermost surface. The flow exhibited a rapid circulation pattern inside the MCZs. The channel flow also exhibited a high degree of interaction with the MCZs. Experimental investigation of the flow pattern in the combustor showed similarities to the computational fluid dynamic results.

INTRODUCTION

The development of efficient air-breathing jet propulsion engines that produce low levels of pollutants in the exhaust will require an improved understanding of the flow and reaction processes that take place in combustion chambers. These processes include atomization and vaporization, when liquid fuels are used, and transport, mixing, and chemical reaction, for both liquid and gaseous fuels. Computational fluid mechanics is a technique for studying these processes without the need for excessive experimental runs.

A flow visualization study of the mixing pattern in a reverse flow combustor was conducted (Figure 1). A transparent model was constructed to examine the flow pattern and mixing of side-mounted turbulent jets and their interaction with the main channel flow. The portion of the combustor volume that was investigated consisted of

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A THERMAL NO_X PREDICTION MODEL: SCALAR COMPUTATION MODULE FOR CFD CODES WITH FLUID AND KINETIC EFFECTS

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Cleveland State University
Cleveland, Ohio 44115

and

Kue Chun
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ABSTRACT

A model was developed to interface with a CFD, k-ϵ based code. A converged solution from the CFD code is the input to the post-processing model for prediction of thermal NO_x. The model uses a decoupled analysis to estimate the equilibrium level of $(NO_x)_e$ which in turn is used to predict its rate of formation, $(dNO_x/dt)_e$, at each node. The rate is fixed in the NO_x production rate plot by estimating the time to reach equilibrium, $(t)_{eq}$, by a differential analysis based on the reaction: $O + N_2 \rightarrow NO + N$. The rate is integrated in the non-equilibrium time space based on the residence time at each node in the computational domain. The sum of all nodal predictions yields the total NO_x level from the combustor. Advantages of this model include: (1) use of all parametric variables of interest for optimization (T, P, $N_2, O_2, NO_e, \mu, p, \epsilon_{ke}, V_m, d_n, N_{re}, D_{ef}, \lambda_o, A$), (2) turbulent mixing effects, (3) geometric effects, (4) lean-to-rich burn combustion conditions, and (5) the potential to work with most k-ϵ based CFD codes.

A COMPARISON STUDY OF STRAIGHT AND CIRCULAR TUBE COMBUSTORS

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ABSTRACT

A Numerical study was conducted using a CFD, k-e based code [ ]. The objective of the study was to compare two combustor configurations i.e., a straight tube combustor and a reverse-low circular combustor. Each of these geometries were further subdivided into one containing the concept of Mini-Combustion-Zones (MCZ) and the other without any compartmentization. The model with MCZ's contained internal baffles and multiple fuel injection ports. The other model contained only a series of multiple injection ports. A one-to-one comparison was made between straight and circular tube combustors with and without MCZ's. The objective was to identify a geometry that could provide complete and immediate combustion of fuel by using the entire combustor space as well as a uniform temperature at the exit of the combustor. The uniformity of temperature was used as a measure of the goodness of mixing.

INTRODUCTION

A COMPARISON OF FLOW VISUALIZATION EXPERIMENTS WITH COMPUTATIONAL FLUID DYNAMIC SIMULATIONS OF A CIRCULAR COMBUSTOR WITH MINI-COMBUSTION ZONES

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and

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ABSTRACT

Flow visualization experiments were performed to study the nature of complex flow pattern in a circular combustor containing mini-combustion zones (MCZs). The MCZs were structured by bell-shaped baffles located along the inner walls. The premise was that a series of baffles placed along the wall of the combustor could enhance mixing and better utilize the combustor volume. Complex flow patterns were visualized and were photographed with a high speed camera. The results were analyzed and compared to computational fluid dynamic predictions from the Fluent code [1]. The simulations were performed at idle and cruise conditions.

The flow visualization studies examined the mixing effects of two air-blast nozzle designs. One nozzle was a standard expanding turbulent jet atomizer and the other was an air-blast atomizer for turbine engines with a 45 degree swirl vane generating 20 to 60 micron droplets. Using the uniformity of temperature as an indirect measure of goodness of mixing, it was determined that a combustor with mini-combustion zones has definite advantages over a straight-through combustor. Idle and cruise conditions showed similar results in flow pattern in the range of $M = 0.1$ to 1.0 as determined by simulations.

This study also examines the interaction of the airblast nozzle in the mini-combustion zone (MCZ) with the main channel flow. Rapid mixing of combustion products with the main channel flow and the minimization of temperature non-uniformity would minimize NOx generation. The results show a mechanism of mixing which is conducive to reducing nitric oxides in turbine combustors.

OPTIMIZATION STUDIES OF A REVERSE FLOW CIRCULAR COMBUSTOR WITH MCZ'S

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ABSTRACT

A numerical study was conducted using a CFD, k-e based code [ ]. The objective of the study was to optimize the design of a reverse flow circular combustor [ ]. The circular combustor combines a circular geometry with multiple fuel injection nozzles in the Mini-Combustion-Zones (MCZ). The concept of MCZ's was incorporated by having a series of injection ports and baffles, figure [ ], whereby each injection nozzle and its surrounding baffles would comprise an MCZ.

An overall combustor model was developed and was used to determine the effects of nozzle position, fuel spray angle, baffle positions with respect to each other, number of baffles, dimensions of baffles and the location of baffles. Initially the baffles were placed on top and bottom surfaces of the combustor and the optimization studies were performed [ ]. Industrial constraints were later introduced into the design and further studies were performed with baffles placed only on one side. The objective of this study was then to compare these two final design configurations and determine which of these geometries could provide the requirements such as low pressure drop within the combustor, uniform temperature at the exit of the combustor (a measure of goodness of mixing), as well as complete and immediate combustion of fuel by using the entire combustor space.

A NUMERICAL SIMULATION OF THE EFFECTS OF POSITION AND SPRAY ANGLE OF THE FUEL INJECTION NOZZLE ON MIXING IN A CIRCULAR COMBUSTOR

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ABSTRACT

A Numerical study was conducted using Fluent computer program developed by Creare, Inc. The objective was to determine the flow pattern between two sets of baffles in an experimental reverse-flow circular combustor, designed for enhanced mixing and NO_x reduction,by varying the position and spray angle of the fuel injection nozzles. The segment of the combustor that was investigated consisted of two baffles positioned on the upperface and two on the lowerface of the circular combustor. Heated air at 300°F and 3 atmospheres pressure was introduced into the combustor with an inlet velocity of 100 ft/sec. The fuel, pentane, was introduced into the main stream via fuel injection nozzles. There were four nozzles, two on the upper and two on the

NUMERICAL SIMULATION OF FLOW AND THE EFFECT OF BAFFLE ARRANGEMENT ON PRESSURE DROP AND TEMPERATURE PATTERN IN A CIRCULAR COMBUSTOR

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ABSTRACT

A numerical simulation study was conducted to determine the effect of baffle arrangement on pressure drop in an experimental reverse-flow circular combustor with several Mini-combustion Zones (MCZ). The Fluent computer code developed by Creare Inc., was used for this study. Three parameters which appeared to significantly affect the pressure drop were varied, and pressure drop for each case was numerically determined. The portion of the combustor volume that was investigated had two baffles on the upper face and two baffles on the lower face. Heated air at 1000°F with an inlet air velocity of 100 ft/sec and 1 atmosphere pressure was introduced into the combustor. Fuel (pentane) at 80°F was introduced via nozzles which were placed between the baffles. The following changes were then made in the baffle arrangement and the effects on the pressure drop and temperature distribution were evaluated for each of the following cases:

1. The positions of the baffles on the upper and lower face were changed.
2. The dimensions of the baffles were varied.
3. The shapes of the baffles were altered.

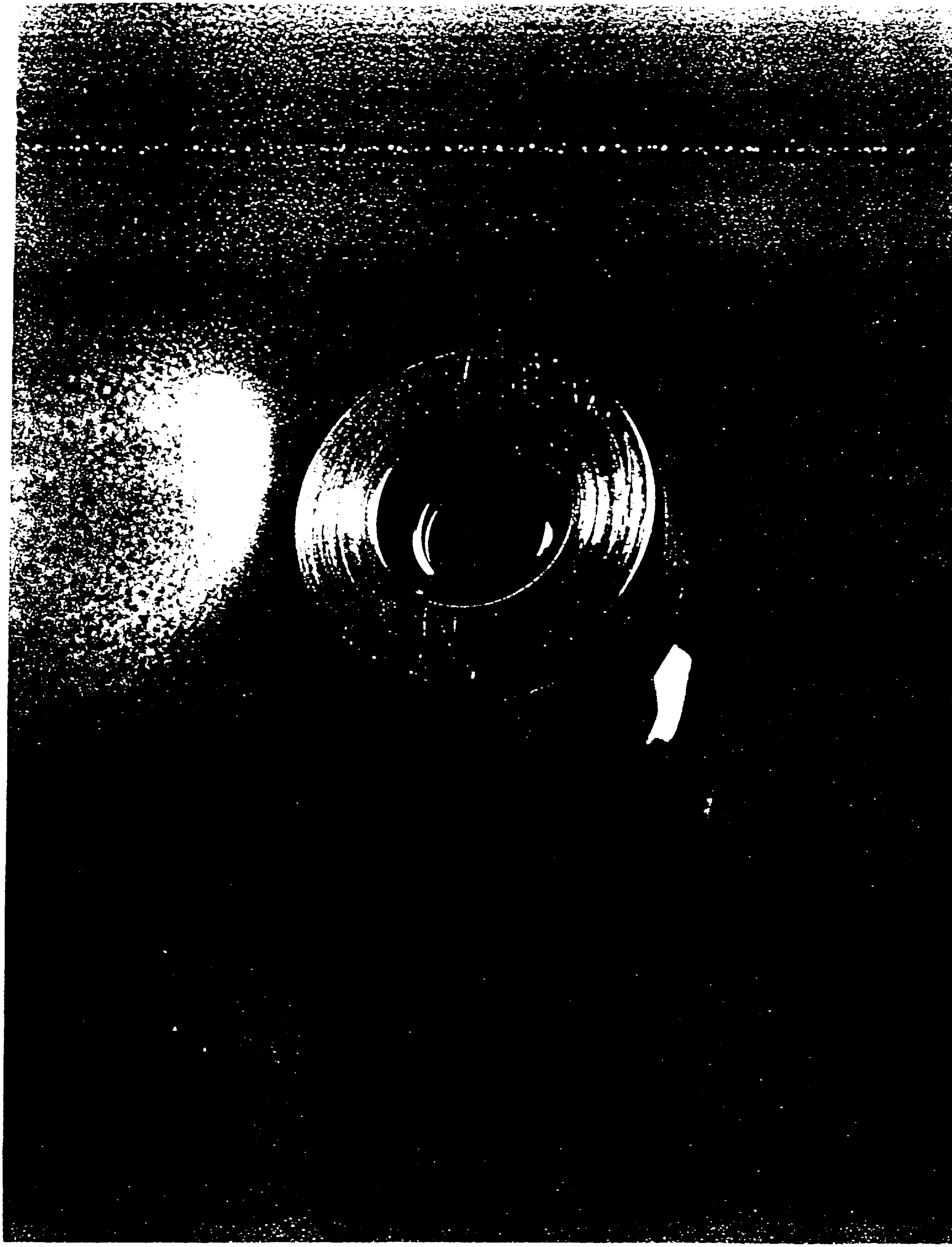
The effects of the above mentioned design alterations are summarized.

KEYWORDS

Mini-combustion-zones; baffles; pressure drop; combustor.

INTRODUCTION

A reverse-flow circular combustor based on the design proposed by Ghorashi [1,2,3] in 1987 was studied. This approach introduces the concept of Mini-Combustion-Zones (MCZ) to use the entire reactor volume via radial injection of fuel along the axial main flow. In addition to this, the use of Mini-Combustion-Zones generates recirculation within the MCZs, making each MCZ to behave like a well-stirred reactor.



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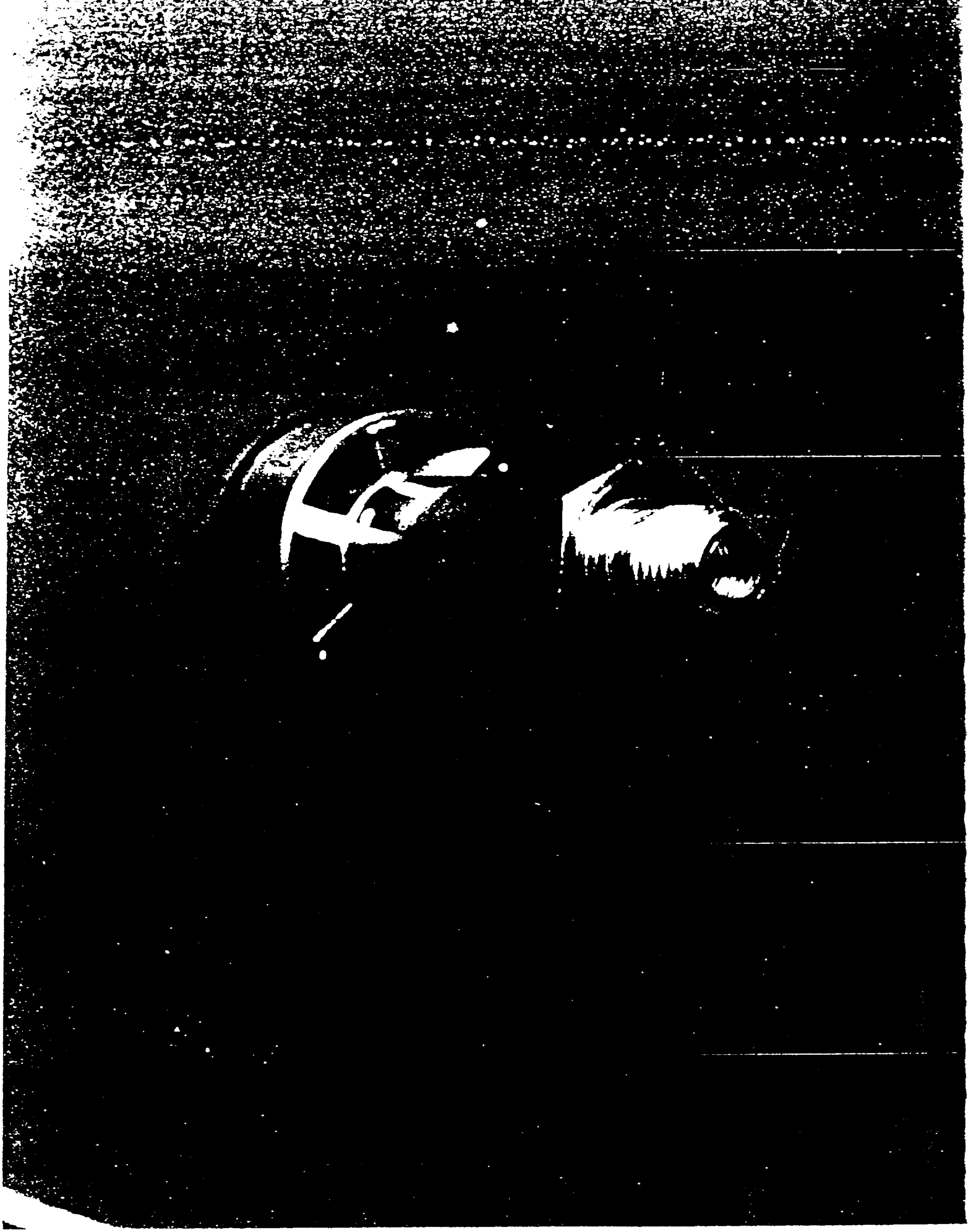

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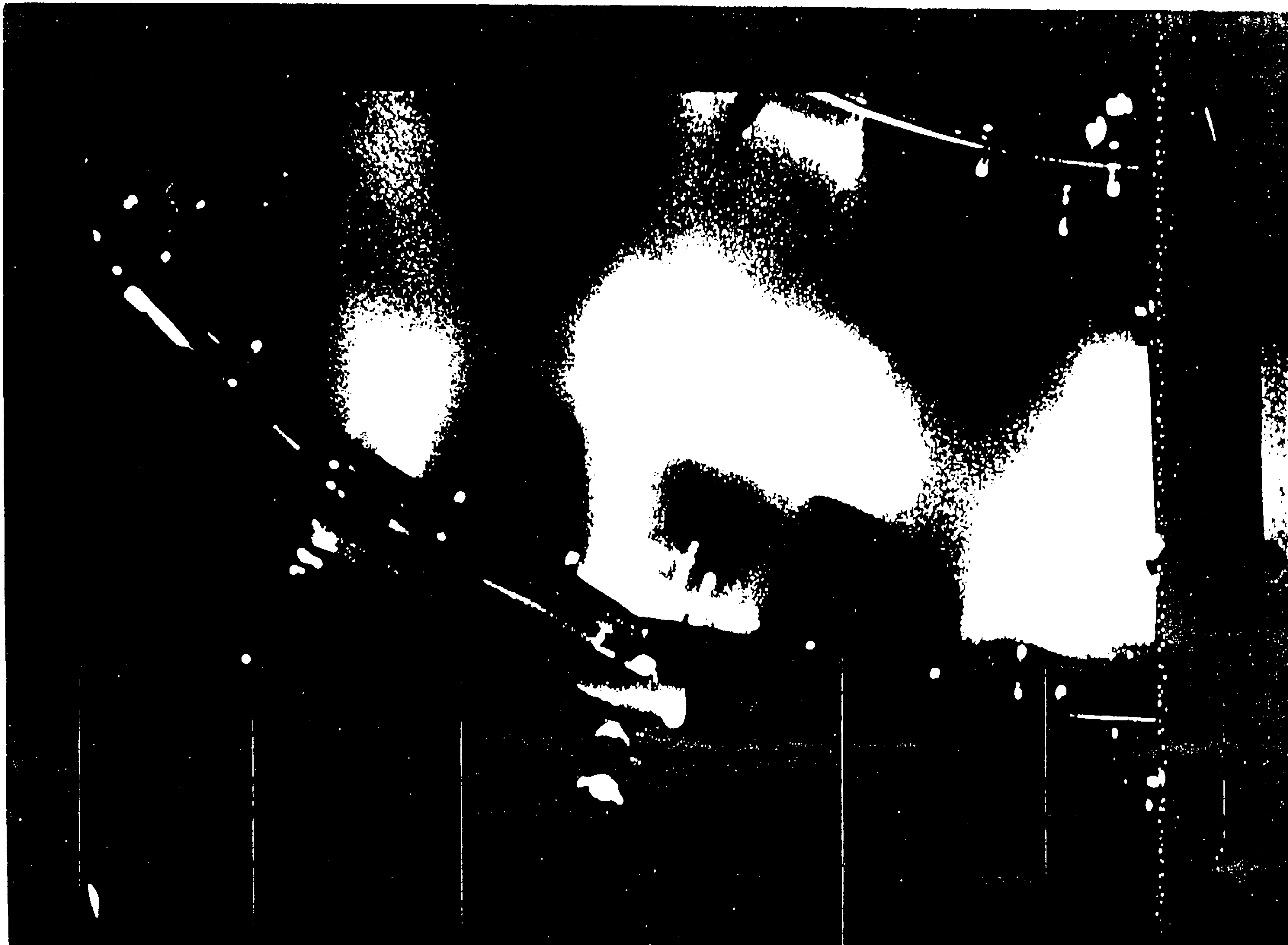


Summary of LDV Results

* Main flow and nozzle flow mixing is indicated by high turbulence intensity values (peaks) at the same location.

* Higher velocities were evident near the inner radius of the combustor.

* Multiple high turbulent intensity peaks in the MCZ indicate significant mixing is occurring.

* Shear layers from baffle peaks interact with nozzle flow increasing local mixing

* Mainflow air adds to the uniformity of mixing across the Y-cross section and enhances the overall mixing in the Y-plane (Area under curve).

* Main flow pressure-increases result in higher axial velocity and lower radial velocities.

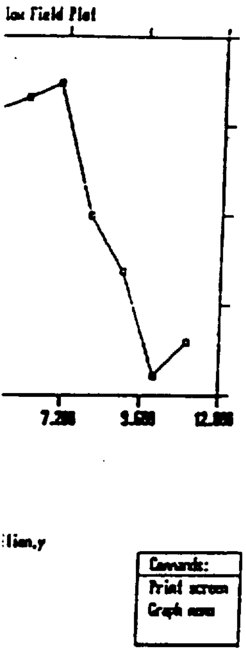
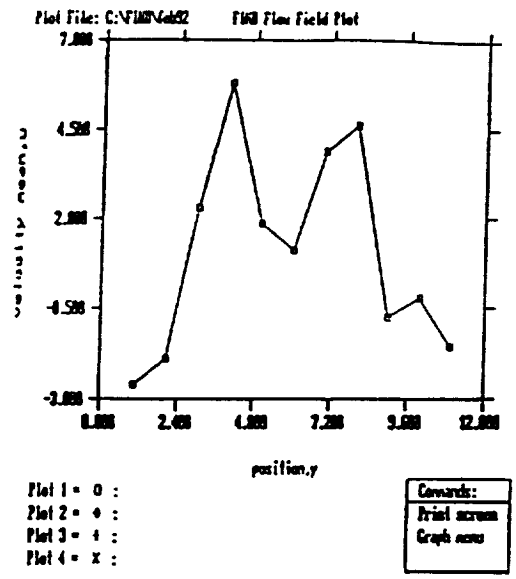
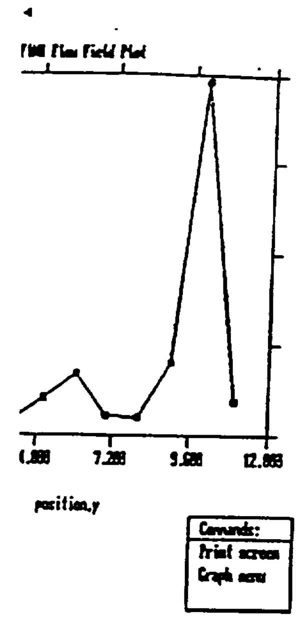
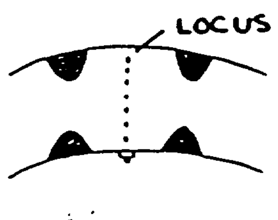


FIGURE 2

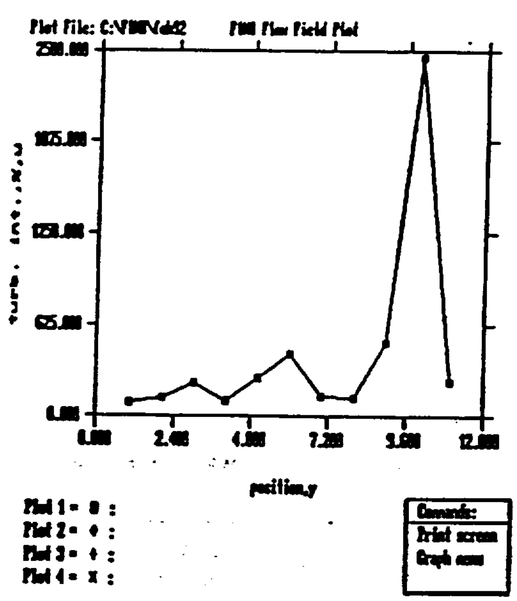






NOZZLE CENTER

FIGURE 4



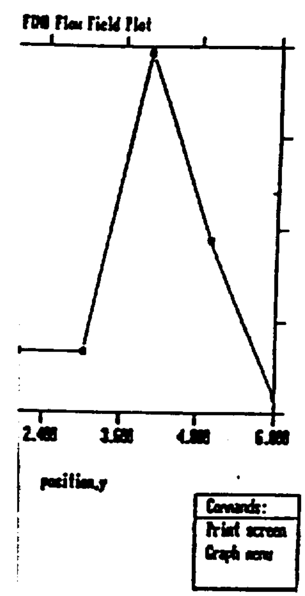


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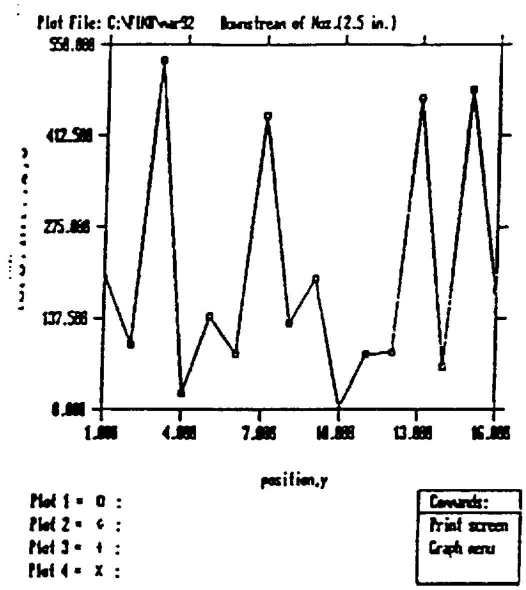
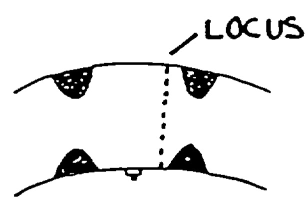
FIGURE 7





VENTURI ENTRANCE

FIGURE 8

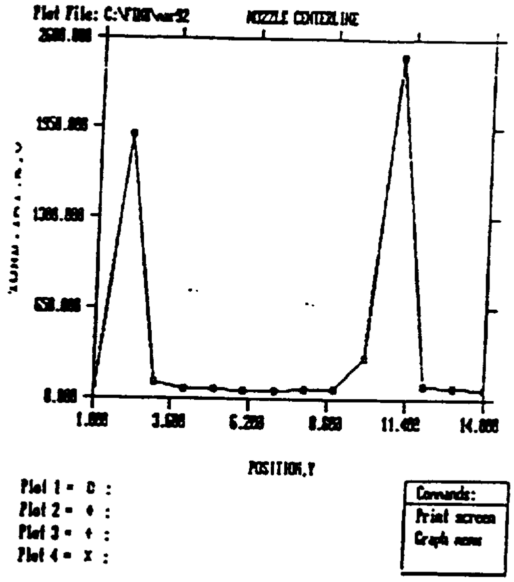
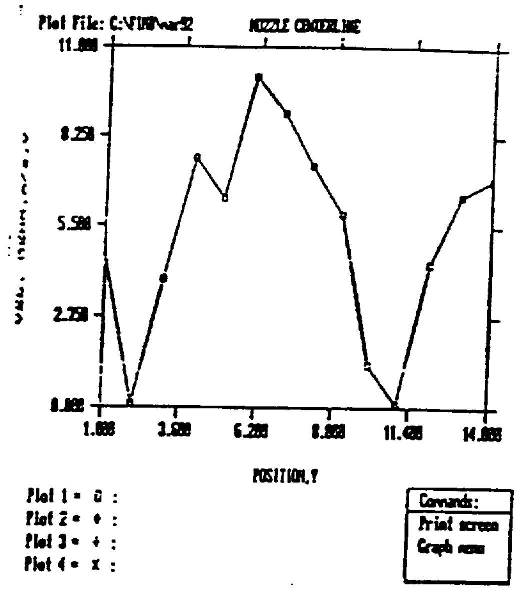
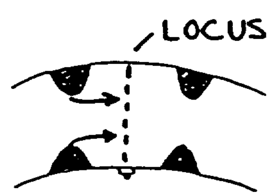


FIGURE 9





NOZZLE CENTER

FIGURE 10

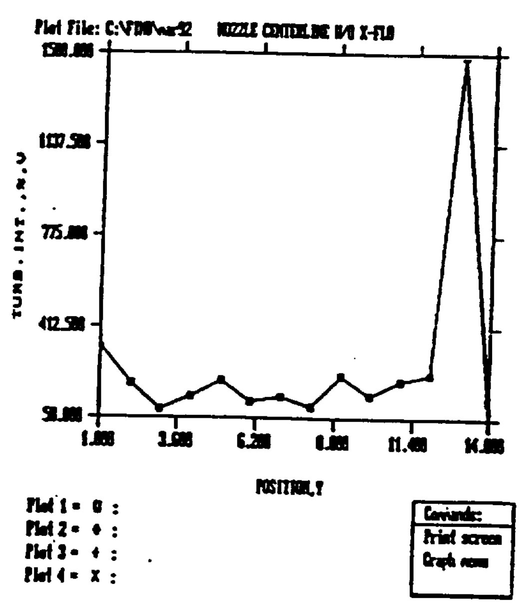


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FIGURE 11

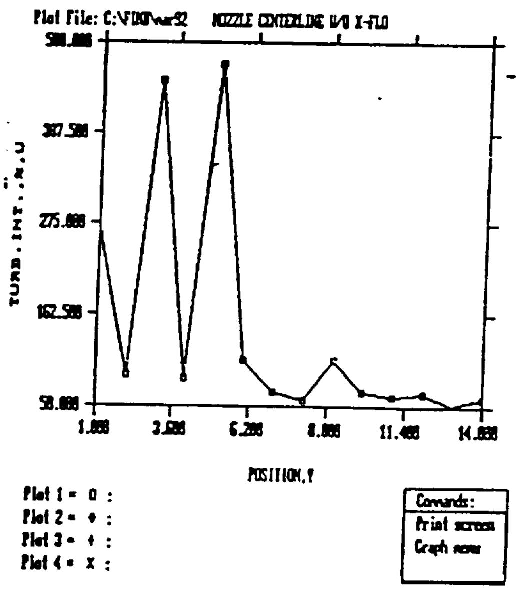
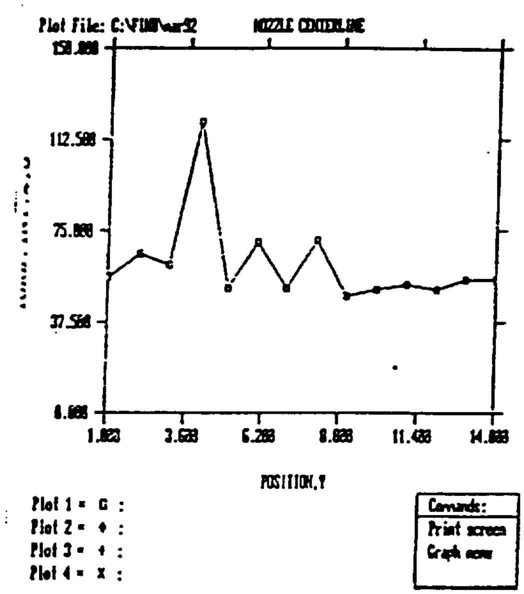
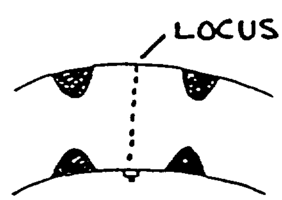
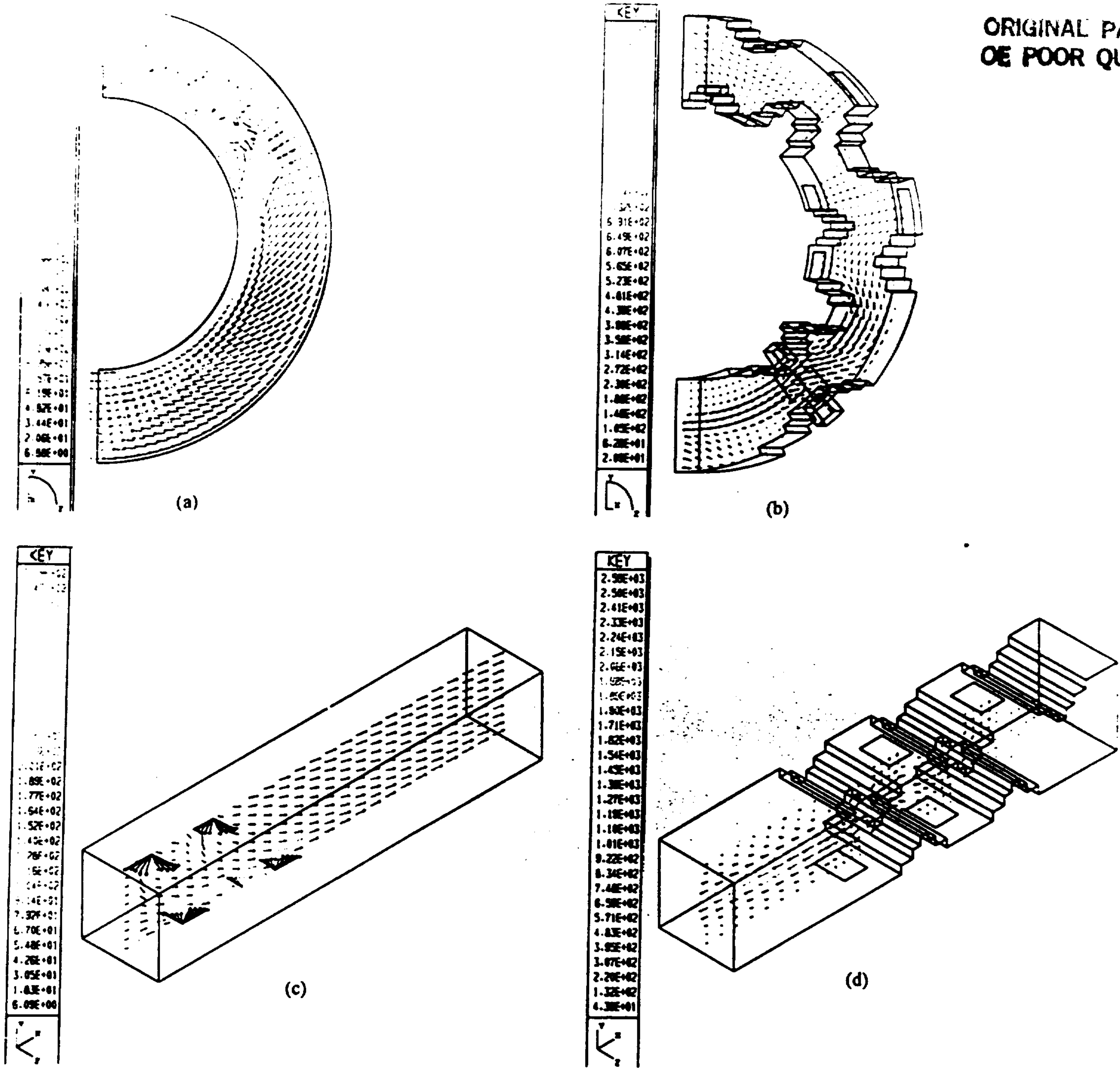


FIGURE 12



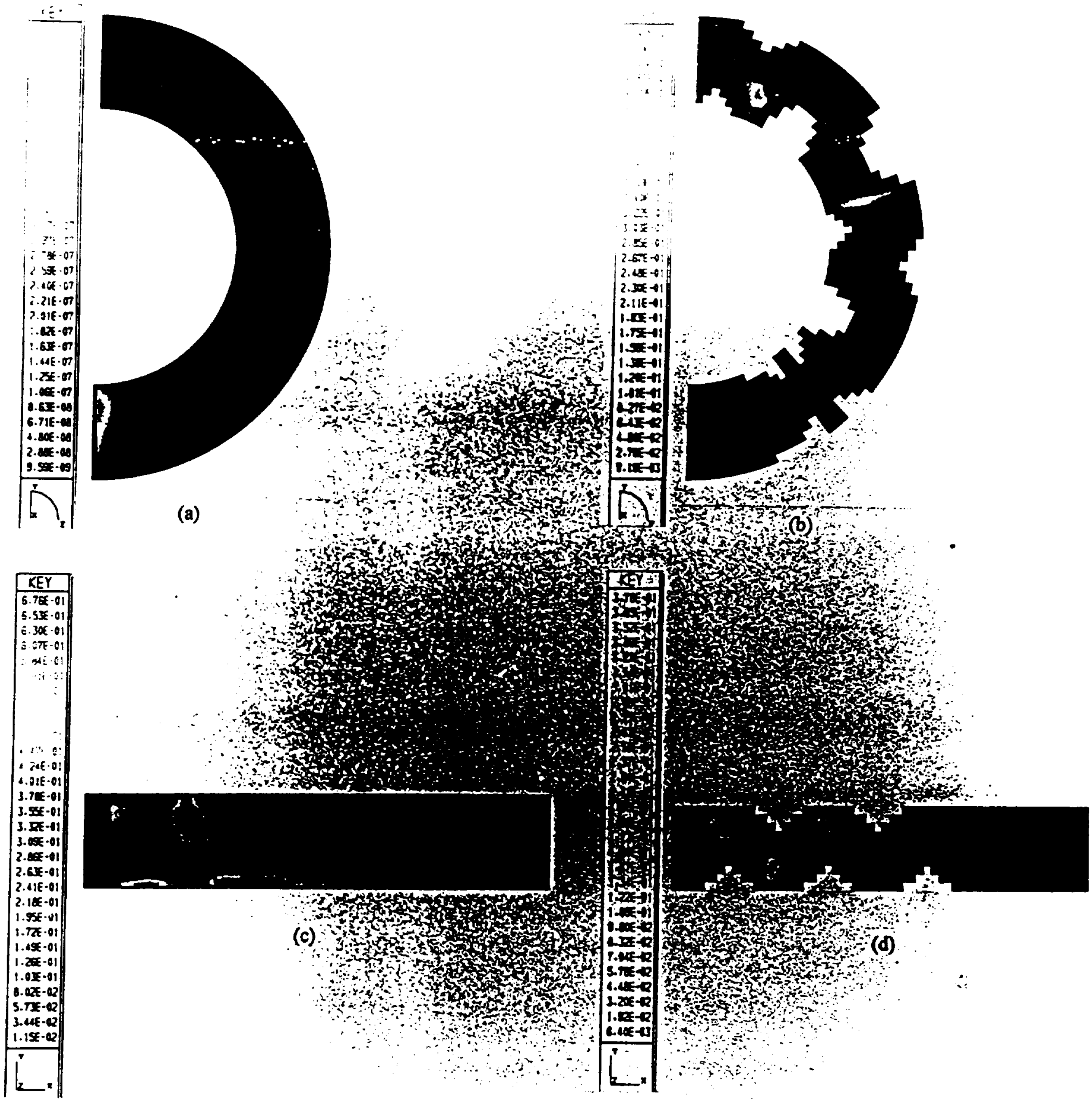


NOZZLE CENTER



COMPARISION OF COMPUTER SIMULATION RESULTS
FOR VELOCITY VECTORS
VELOCITY FT/SEC
ORIENTATION X, PALNE 6, 3 - D DOMAIN

(a) - Circular, no Baffles (b) - Circular, Baffles
(c) - Straight, no Baffles (d) - Straight, Baffles



COMPARISION OF COMPUTER SIMULATION RESULTS
FOR C8H18 MASS FRACTION
MASS FRACTION DIMENSIONLESS
ORIENTATION X, PALNE 6, 3 - D DOMAIN

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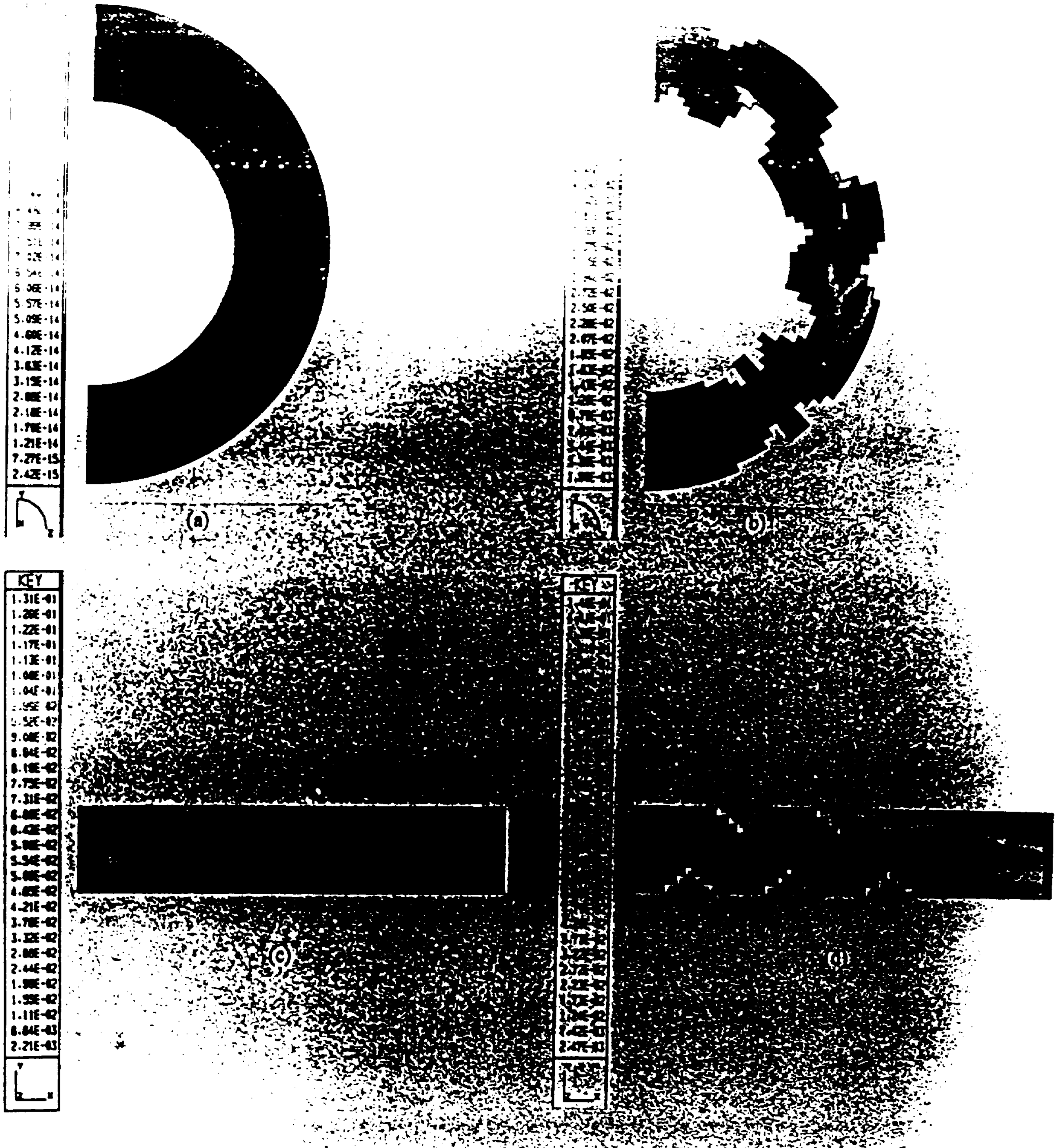
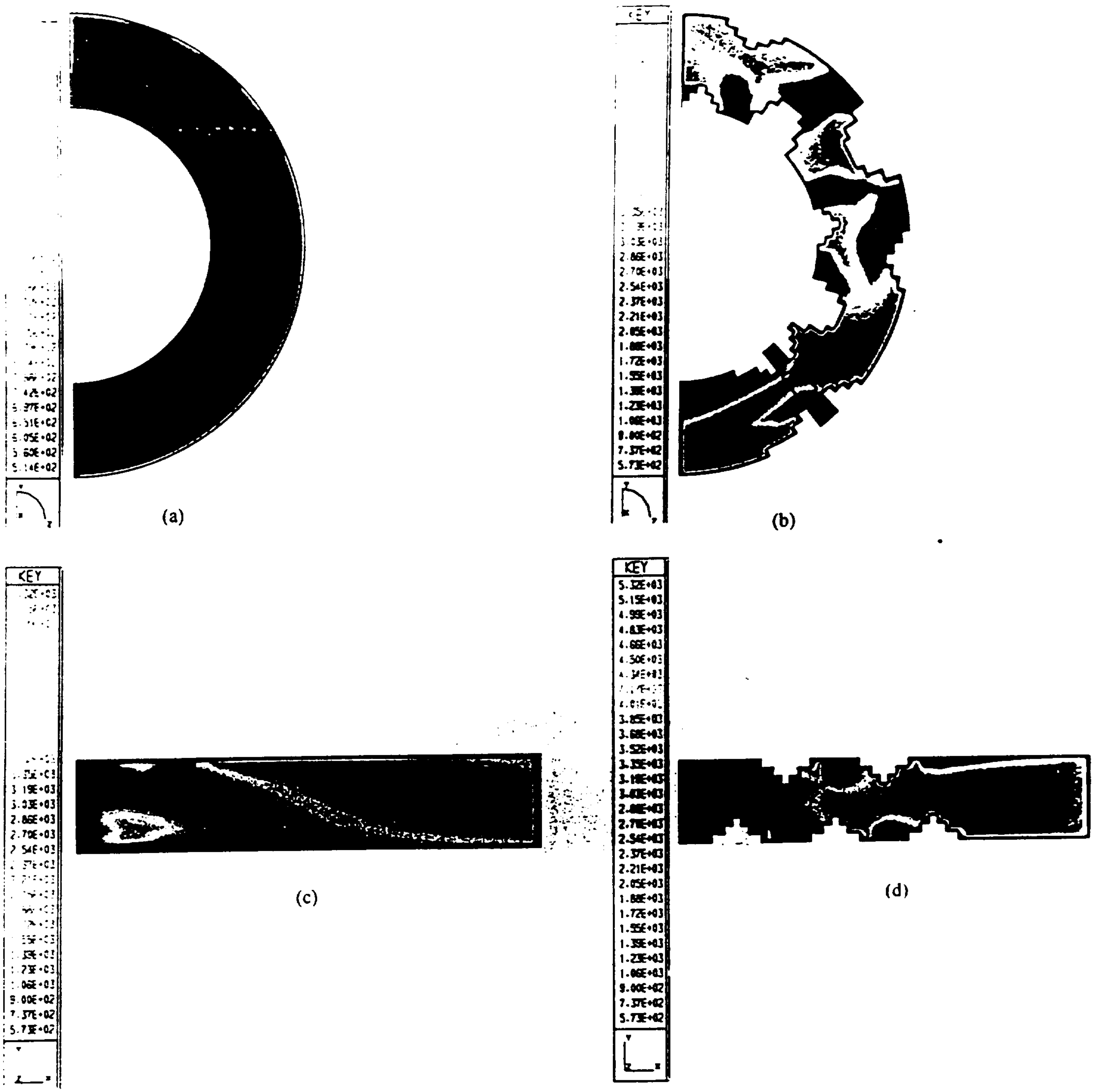
(c) - Straight, no Baffles (d) - Straight, Baffles



COMPARISION OF COMPUTER SIMULATION RESULTS
FOR CO MASS FRACTION
MASS FRACTION DIMENSIONLESS
ORIENTATION X, PALNE 6, 3 - D DOMAIN

(a) - Circular, no Baffles (b) - Circular, Baffles
(c) - Straight, no Baffles (d) - Straight, Baffles



COMPARISION OF COMPUTER SIMULATION RESULTS
FOR TEMPERATURE PATTERN
TEMPERATURE IN DEGREE RANKINE
ORIENTATION X, PALNE 6, 3 - D DOMAIN

(a) - Circular, no Baffles (b) - Circular, Baffles
(c) - Straight, no Baffles (d) - Straight, Baffles

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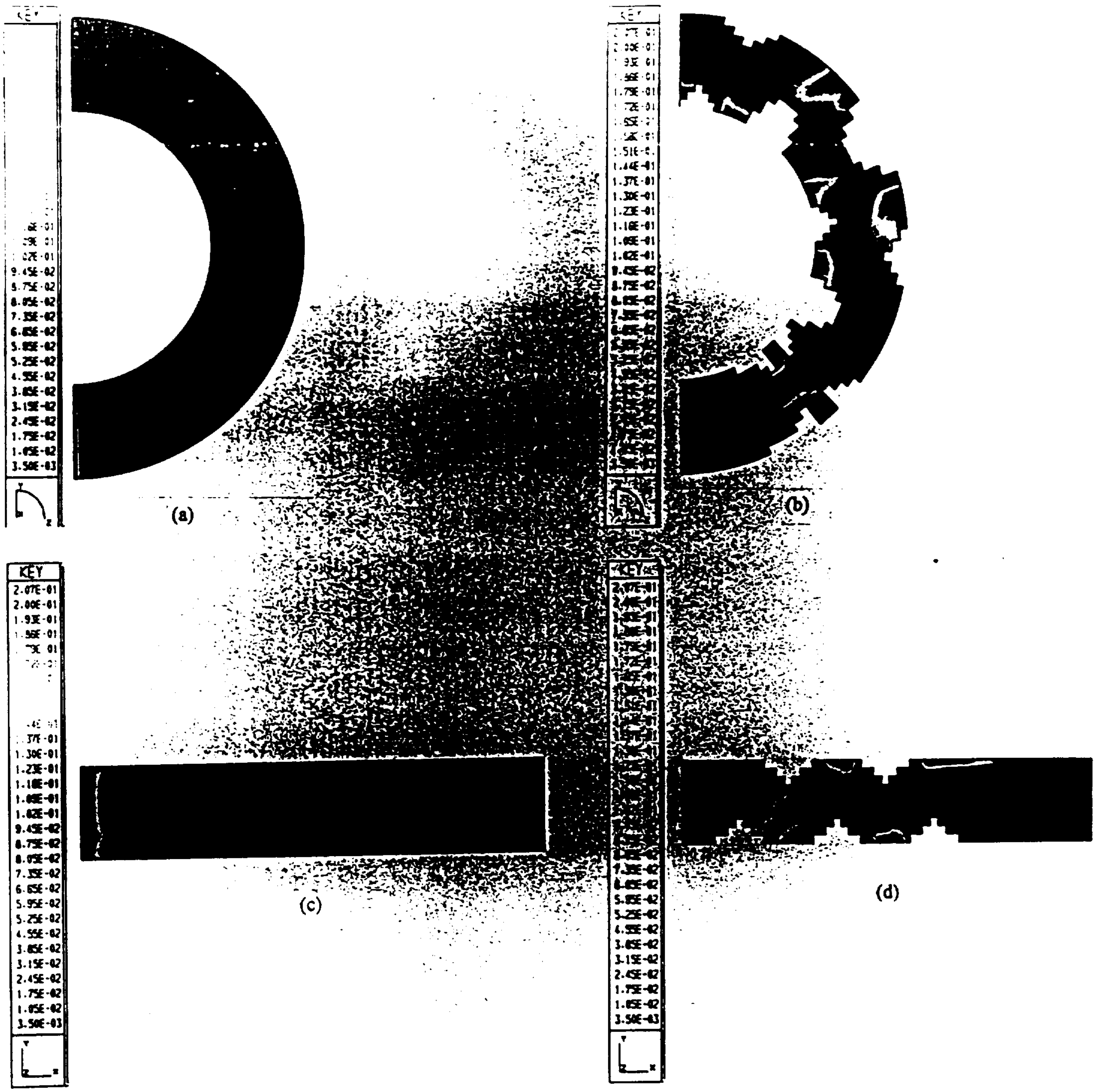
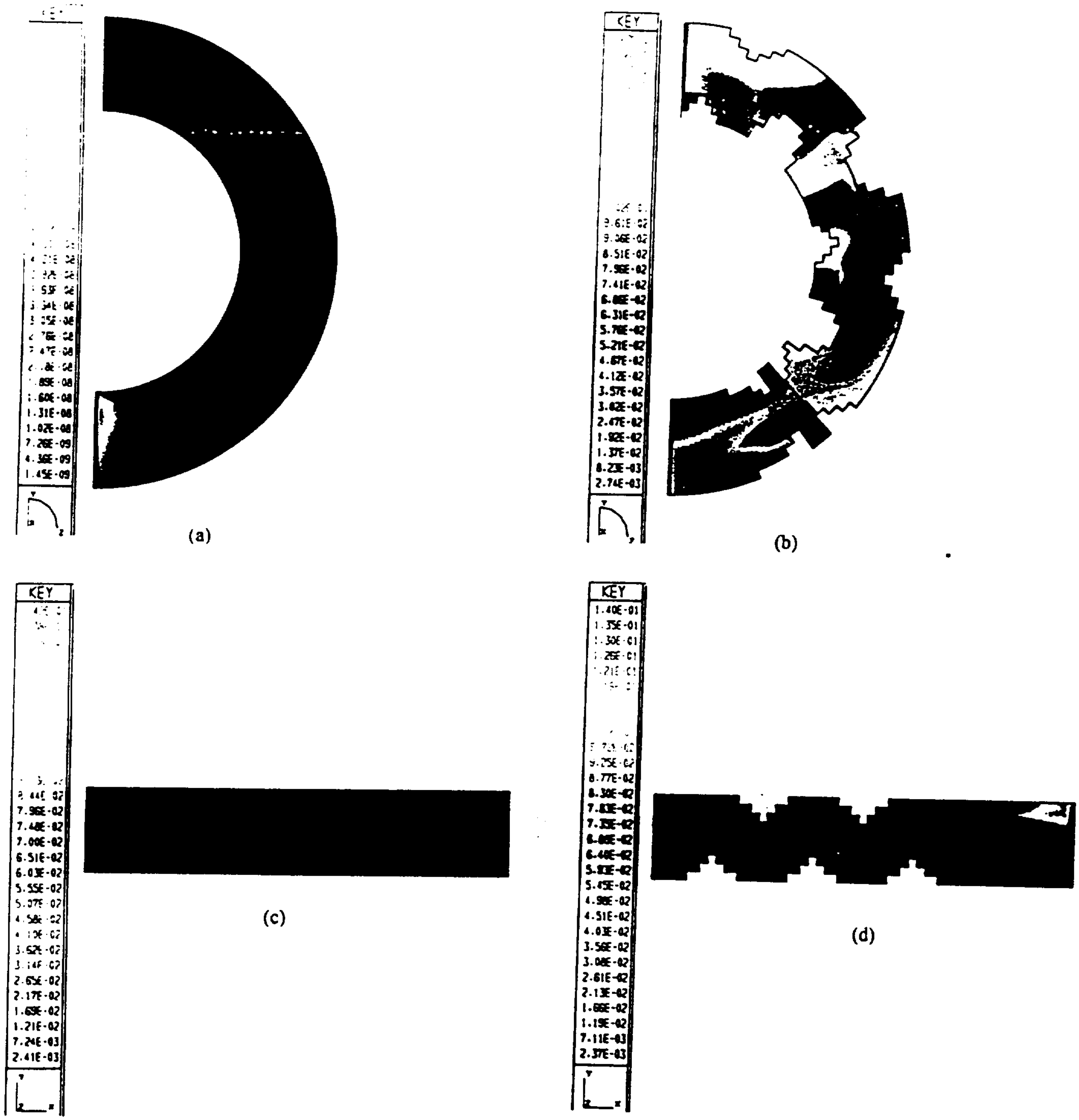


COMPARISION OF COMPUTER SIMULATION RESULTS
FOR O2 MASS FRACTION
MASS FRACTION DIMENSIONLESS
ORIENTATION X, PALNE 6, 3 - D DOMAIN

(a) - Circular, no Baffles (b) - Circular, Baffles
(c) - Straight, no Baffles (d) - Straight, Baffles



COMPARISION OF COMPUTER SIMULATION RESULTS
FOR CO2 MASS FRACTION
MASS FRACTION DIMENSIONLESS
ORIENTATION X, PALNE 6, 3 - D DOMAIN

(a) - Circular, no Baffles (b) - Circular, Baffles
(c) - Straight, no Baffles (d) - Straight, Baffles

THERMAL NO_X PREDICTION MODEL

PROCEDURE:

Converged Fluent Case (k-epsilon Model)

1. INPUT:

Pressure
Temperature
Oxygen Concentration
Nitrogen Concentration
Eddy Dissipation
Effective Viscocity
Density
Velocity Magnitude

2. **Calculate Effective Diameter (D_e) and the Cross-Sectional Area (A_x) of the Combustor at Each ~~Node~~**
Plane

$$D_e = 4 * \text{Area} / \text{Perimeter}$$
$$A_x = L * W$$

3. **Calculate Kolmogorov Length Scale at Each Node**

$$\lambda_0 = [(\mu/\rho)^3/\varepsilon]^{0.25}$$

4. **Calculate Turbulent Reylolds Number at Each Node**

$$N_{RE} = [D_e|V_m|\rho/\mu]$$

5. **Calculate λ_{PM} at Each Node**

$$\lambda_{PM} = \sqrt{(\mu * A / D_e|V_m|\rho)}$$

6. **Calculate the Residence Time for Each Node**

$$t_{RT} = d / |V_m|$$

7. **Test for the Degree of Mixing at Each Node**
(if $0 < \lambda_{PM} / \lambda_0 \leq 1$, go to step A
if $\lambda_{PM} / \lambda_0 = 0$, go to step B)

A. Good Mixing = 2.78 * [Hung's Eq.] (Smith, et.al.)
B. Diffusion Limited Case = 1.00 * [Hung's Eq.]

8. Correct for Nitrogen Conversion at Each Plane (Mass Balance at Each Plane to Determine the Nitrogen Consumption)

Note: Correction for Nitrogen Conversion at each Node Might Yield More Accurate Results, However, it would be Computationally Inefficient. Nontheless, the latter should be tested.

$$[N_2]_0 = 0.79 - 1/2 * \Sigma[NO]_t - \Sigma[N]_t = [N_2]_t$$
$$[NO]_t = 2\gamma t - \gamma/\alpha(1 - e^{-\alpha t})$$
$$[N]_t = 2\beta\gamma t/\alpha + \gamma/\alpha(1 - e^{-\alpha t})$$

where α , β and γ are Determined from the Arhenious Equation

9. Calculate the Equilibrium Values of Oxygen, Nitrogen and Nitric Oxide with 18-Step Octane Combustion Model (Kopa, et.al.)

The number of equilibrium equations is equal to the number of components minus the number of atomic species, that is, four elements in atomic form: C, H, O, N.

$$K_1 = \frac{(O)}{(O_2)^{1/2}} \qquad K_8 = \frac{(C)(H_2)^2}{(CH_4)}$$

$$K_2 = \frac{(O_3)}{(O_2)^{3/2}} \qquad K_9 = \frac{(N)}{(N_2)^{1/2}}$$

$$K_3 = \frac{(H)}{(H_2)^{1/2}} \qquad K_{10} = \frac{(N)(O)}{(NO)}$$

$$K_4 = \frac{(H_2)^2(O_2)}{(H_2O)^2} \qquad K_{11} = \frac{(O_2)^{1/2}(NO)}{(NO_2)}$$

$$K_5 = \frac{(OH)}{(O_2)^{1/2}(H_2)^{1/2}} \qquad K_{12} = \frac{(N_2)^{1/2}(H_2)^{3/2}}{(NH_3)}$$

$$K_6 = \frac{(C)(O_2)}{(CO_2)} \qquad K_{13} = \frac{(NO_2)^3(H_2O)}{(HNO_3)^2(NO)}$$

$$K_7 = \frac{(C)(O_2)^{1/2}}{(CO)} \qquad K_{14} = \frac{(C)(N_2)^{1/2}(H_2)^{1/2}}{(HCN)}$$

Equilibrium Constant K_p as a Function of Absolute Temperature (K)

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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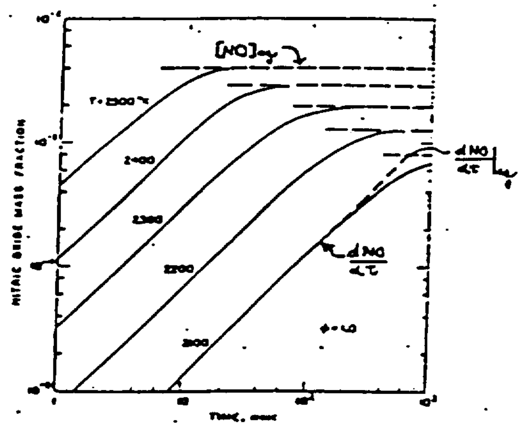
10. **Calculate the Rate of Nitric Oxide Formation at the Intersection of Equilibrium NO and NO Rate-Line, Using the Hung Equation at Each Node**

$$dX_{NO}/dt = P^{1/2}[(aX_{n2}X_{02}^{1/2} - bX_{NO}^2/X_{02}^{1/2}) / (1 + cX_{NO}/X_{02})]$$

Where a,b,c is determined from the Arhenious Equation



11. **Estimate the Relaxation Time Via the Differential Analysis of the Controlling Mechanism**

$$t_{calc} = [NO]_e/2\gamma$$

12. **Calculate the Actual Time Based on Two-Step Mechanism**

$$O + N_2 = NO + N$$
$$N + O_2 = NO + O$$
$$t_{RX} = t_{calc}/2$$

13. **Construct Semi-Log NO_x Formation Rate Curves (refer to Step 10)**

14. **Determine Non-equilibrium NO_x Formation Rates**

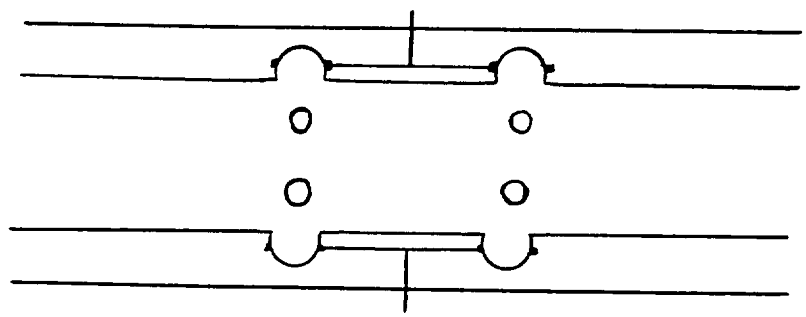
Note: **Interpret Curve to Find Non-equilibrium NO Rate at Lower Limit [t_{RT} * 0.01] and at Upper Limit [t_{RT}].**

15. **Integrate the Rate with respect to Time**

$$NO(i,j) = \int dNO/dt * dt = 0.5 * (t_{RT} - 0.01 * t_{RT}) * \Delta dNO/dt$$

16. **Sum all the Local NO_x Values to Estimate the Total Thermal NO_x**

$$NO_x = \sum_{i,j=1}^{m} NO(i,j) \text{ for } K = 1 \text{ to } N$$



ALTERNATE METHOD

Procedure

Converged FLUENT Case

1. INPUT

Pressure
Temperature
Oxygen Concentration
Nitrogen Concentration
Velocity Magnitude
Assume Constant Nitrogen Concentration

2 Use Global Forward-Rate Reaction to Estimate the Local NO_x Formation

$$[NO] = Ke^{(-k2/T)}[N_2][O_2]^{1/2}t$$

Where [ ] = mole fraction
T = Temperature
t = time
K,K2 = constants

3. Integrate with respect to Residence Time

4. Sum all the Values in order to Obtain the Total Thermal NO_x

Limitations of this Method

1. Temperature Range

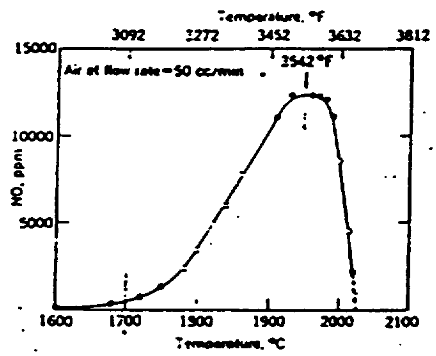


Figure 1. Net NO production as a function of temperature.

$2030\ ^0C < T < 1700\ ^0C$

2. Assumptions

$$dX_{NO}/dt = P^{1/2}[(aX_{N_2}X_{O_2}{}^{1/2}-bX_{NO}{}^2/X_{O_2}{}^{1/2})/(1+\ cX_{NO}/X_{O_2})]$$

if X_{NO} is small, then $(X_{NO})^2 \approx 0$
if X_{NO} is small, then $X_{NO}/X_{o2} \approx 0$

$$[NO] = Ke^{(-k2/T)}[N_2][O_2]^{1/2}t$$

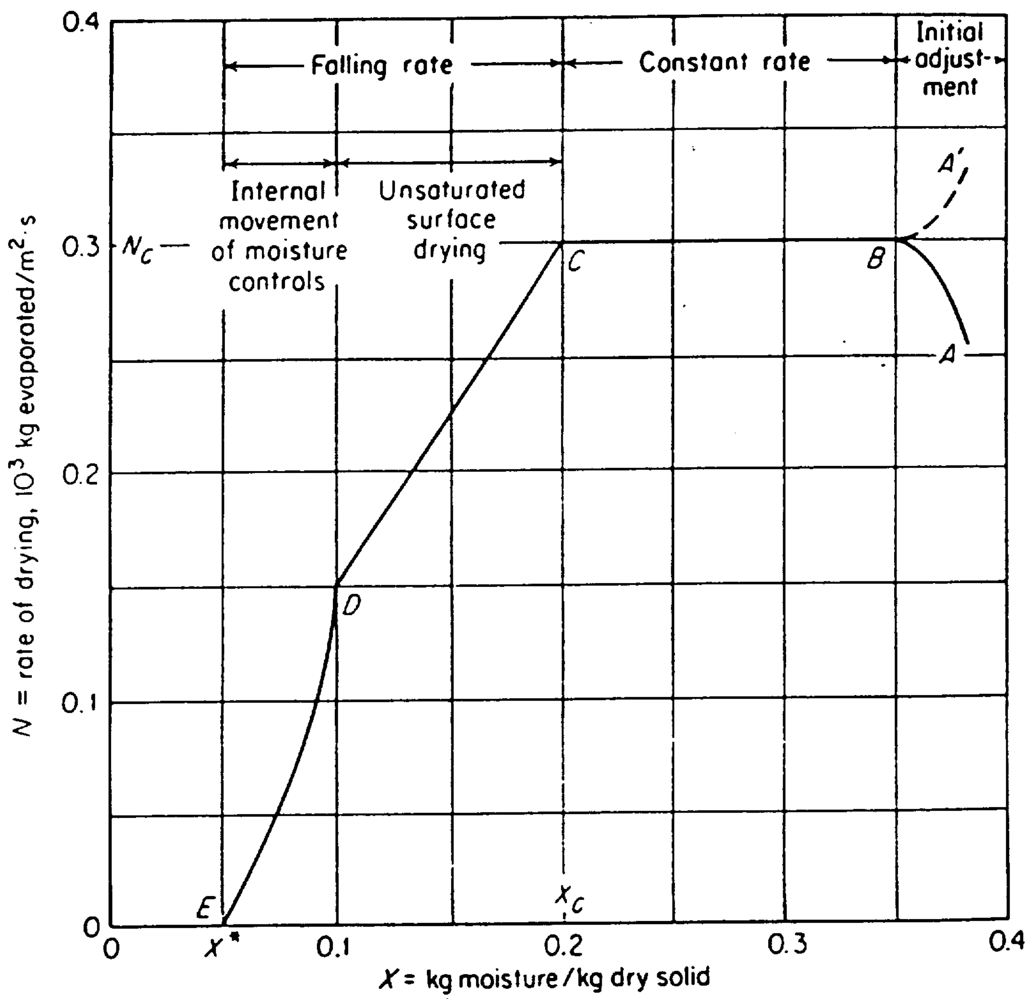


Figure 12.10 Typical rate-of-drying curve, constant drying conditions.

The equivalent molecular diameter is given by equation

$$\sigma = \sqrt{\frac{8.28 \times 10^{-20} \quad T^{1.5}\rho}{\mu P m^{1/2}}}$$

The mass diffusivity can be calculated from:

$$D = \frac{2.628 \times 10^{-19} \sqrt{T^3/M}}{P\sigma^2}$$

The Schmidt number of air is given by

$$(Sc)_{air} = \frac{\mu}{\rho D_{AB}}$$

$$(Sc)_{air} = \frac{\nu}{D_{AB}}$$

For the high-Schmidt-number case, the time constant can be obtained by

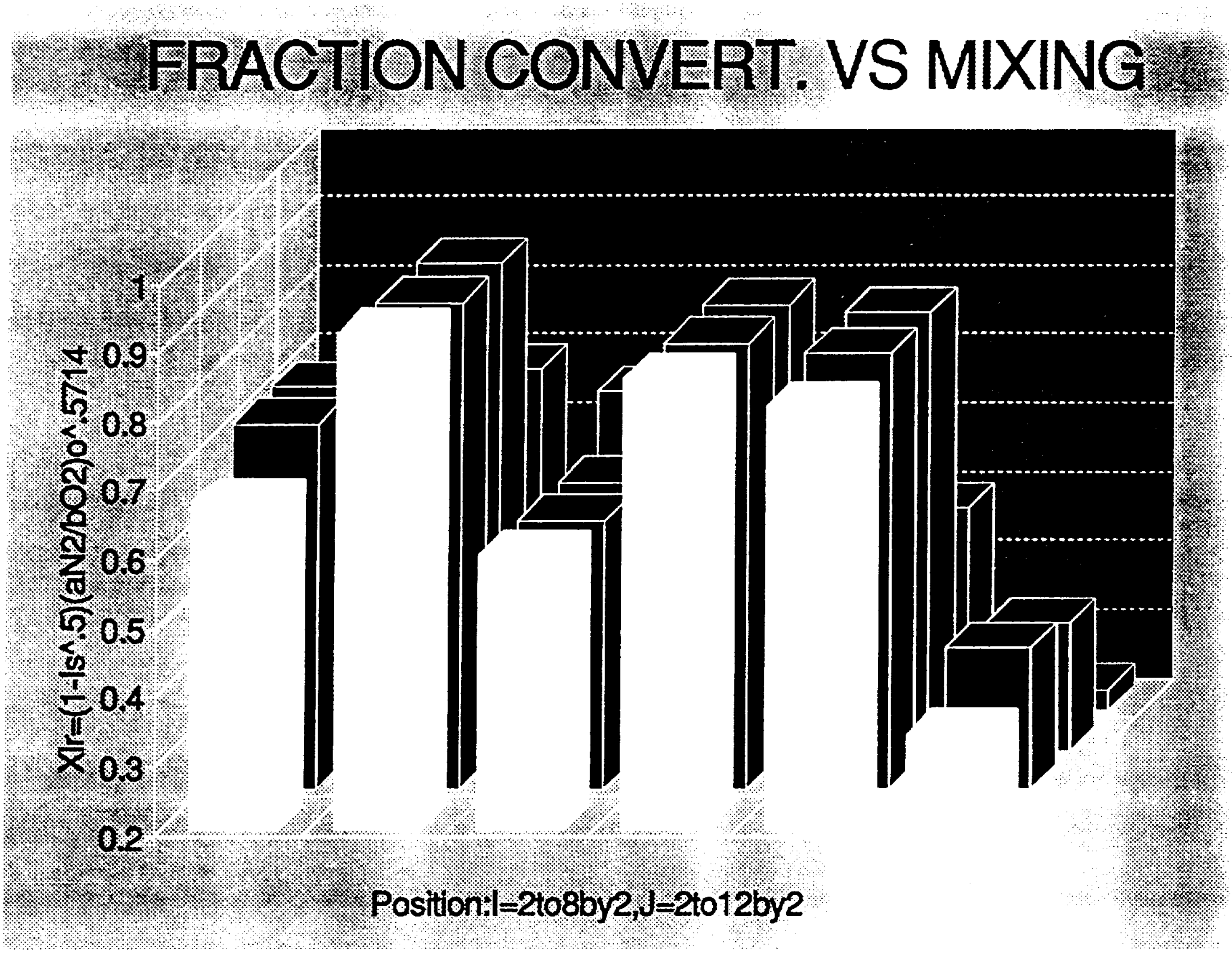
$$\tau = \frac{1}{2}\left[3\left(\frac{5}{\pi}\right)^{2/3}\left(\frac{L_s^2}{\epsilon}\right)^{1/3} + \left(\frac{\nu}{\epsilon}\right)^{1/2} \ln N_{Sc}\right]$$

no mixing in the limit of infinite Schmidt number is now satisfied ($\tau = \infty$, which gives $I_s = 1$ for all time).

The local mixing problem is simplified

$$I_s = \frac{1}{1 + \tau'/\tau}.$$

Isotropic theory as previously presented could be applied to mixing-vessel problems with some degree of approximation. However, in this case the turbulent field will decay in certain regions of the mixer. Probably the only area which would approximate a constant turbulent field is that in the immediate vicinity of the stirrer.


FRACTION CONVERT. VS MIXING
Xlr=(1-ls^.5)(aN2/bO2)o^.5714
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Position:I=2to8by2,J=2to12by2

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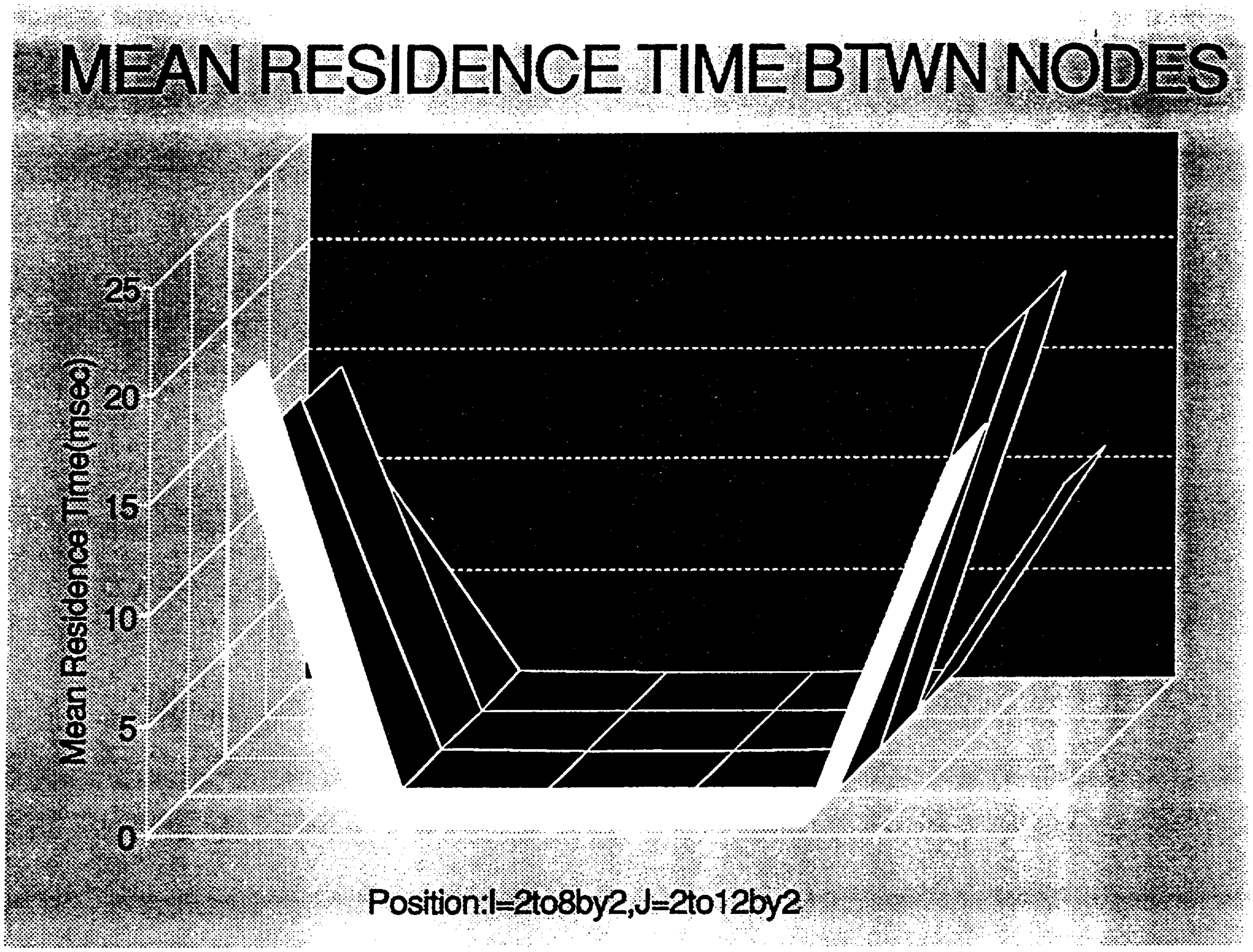
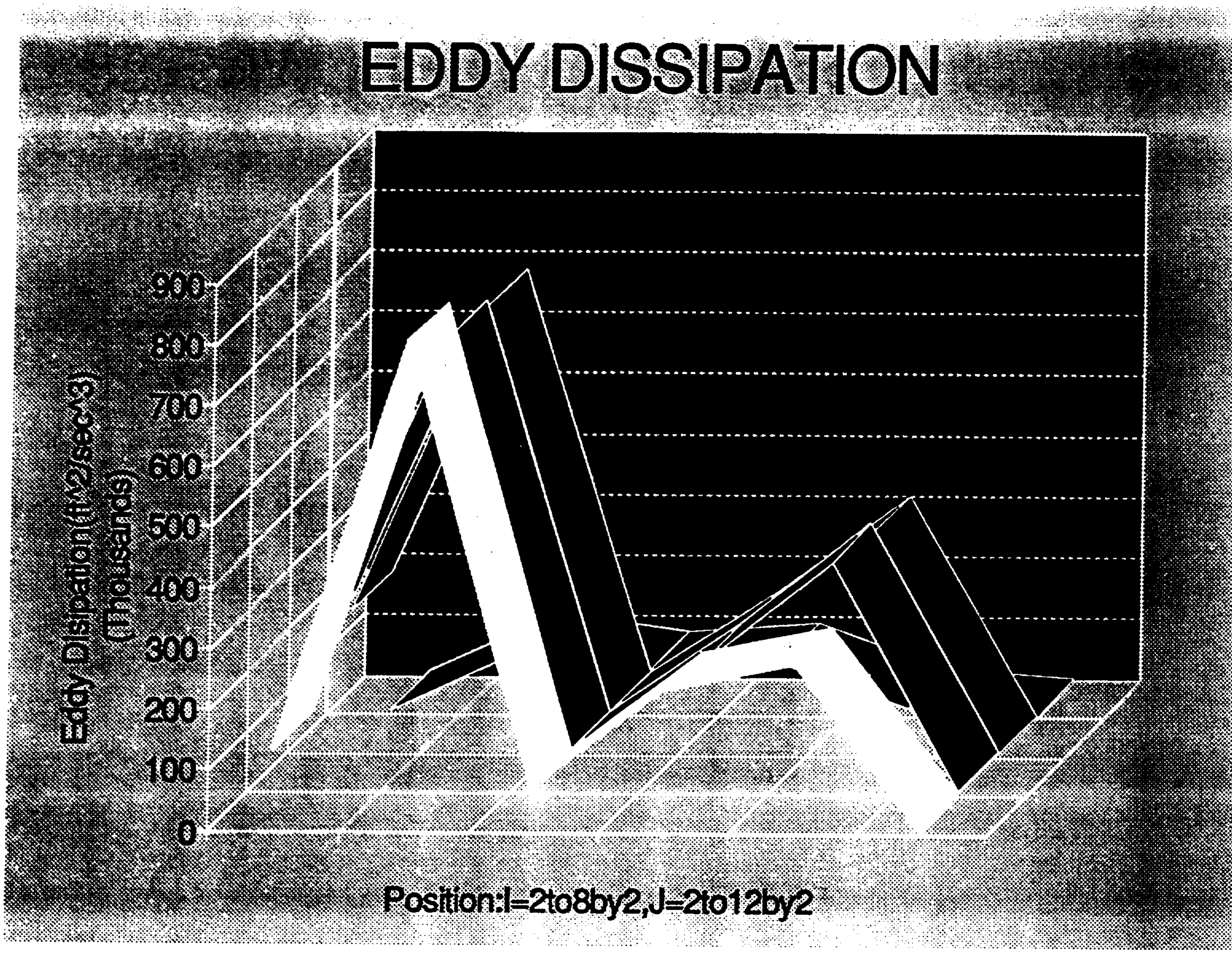
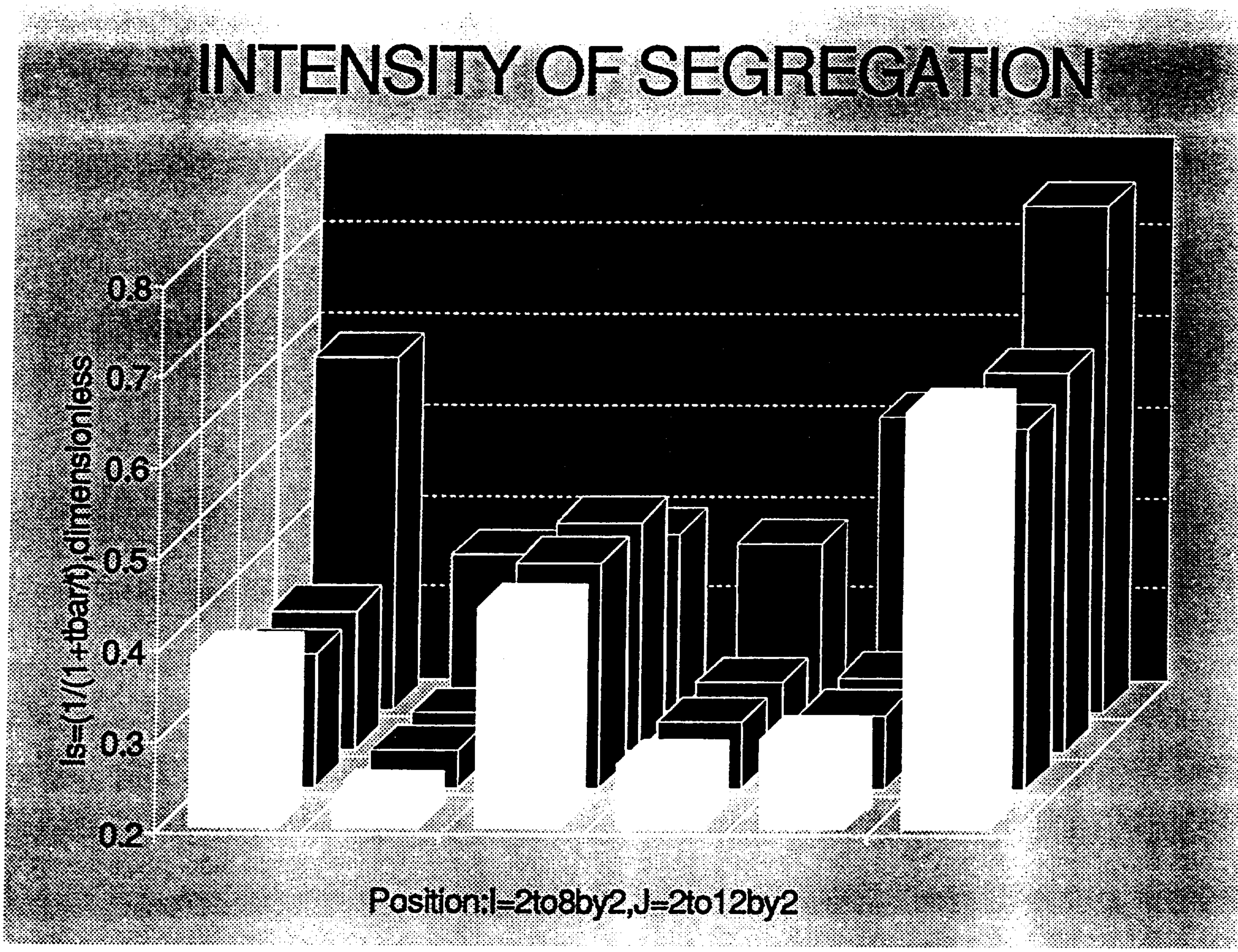



EDDY DISSIPATION
Eddy Dispation(ft^2/sec^3)
(Thousands)
900
800
700
600
500
400
300
200
100
0
Position:I=2to8by2,J=2to12by2


INTENSITY OF SEGREGATION
Is=(1/(1+tbar/t)),dimensionless
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Position:I=2to8by2,J=2to12by2

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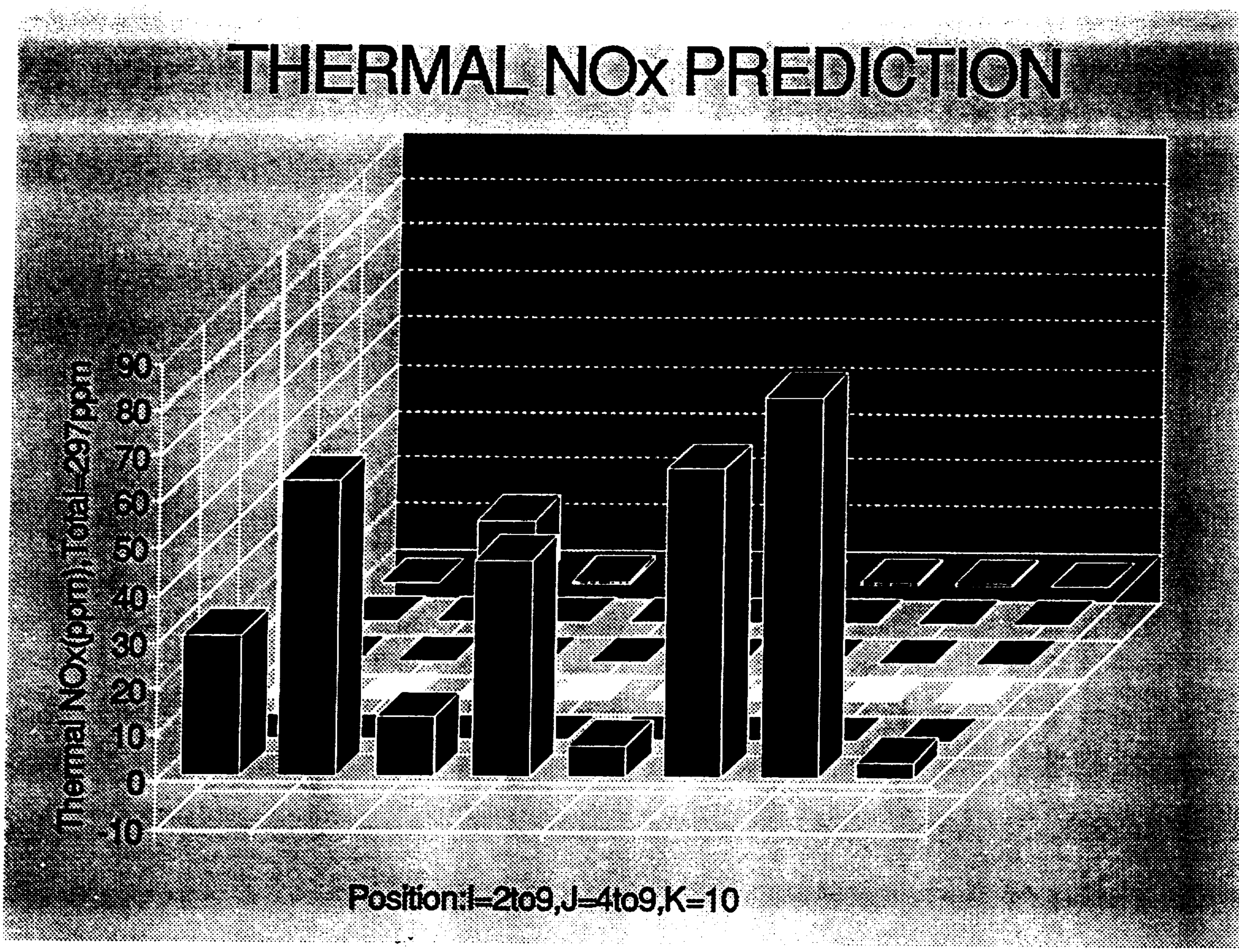
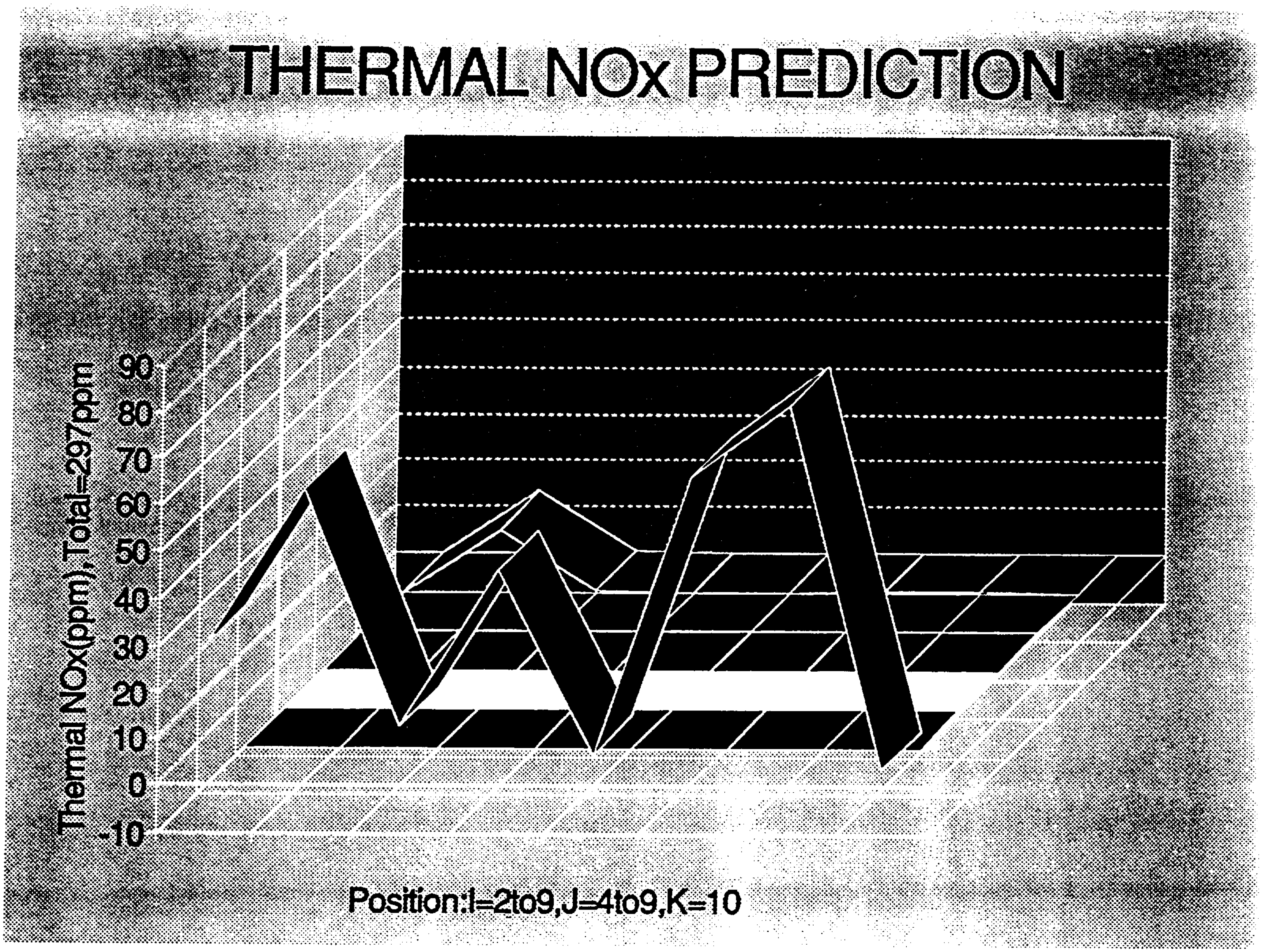
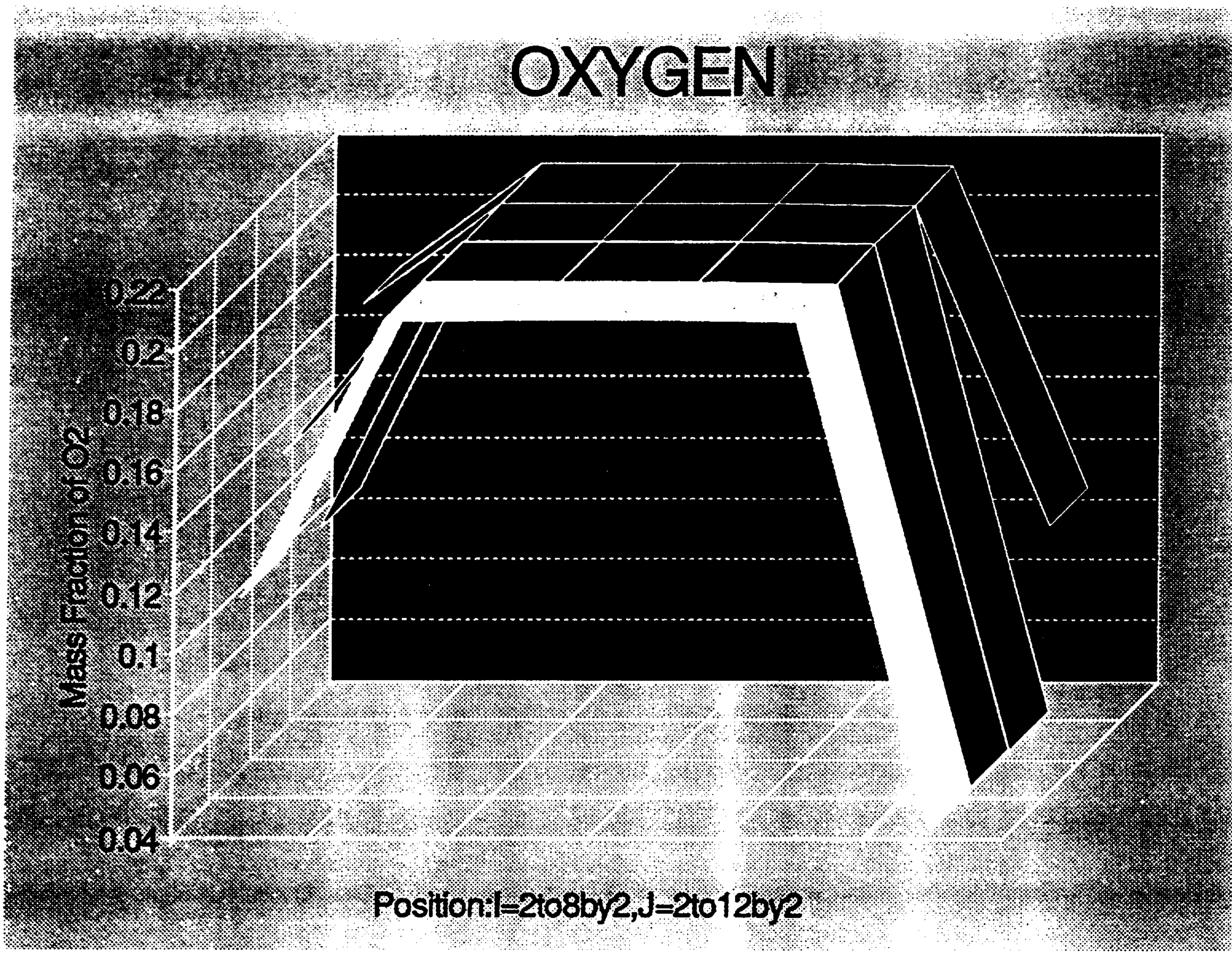



THERMAL NOx PREDICTION
Thermal NOx(ppm),Total=297ppm
90
80
70
60
50
40
30
20
10
0
-10
Position:I=2to9,J=4to9,K=10


OXYGEN
Mass Fraction of O2
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
Position:I=2to8by2,J=2to12by2

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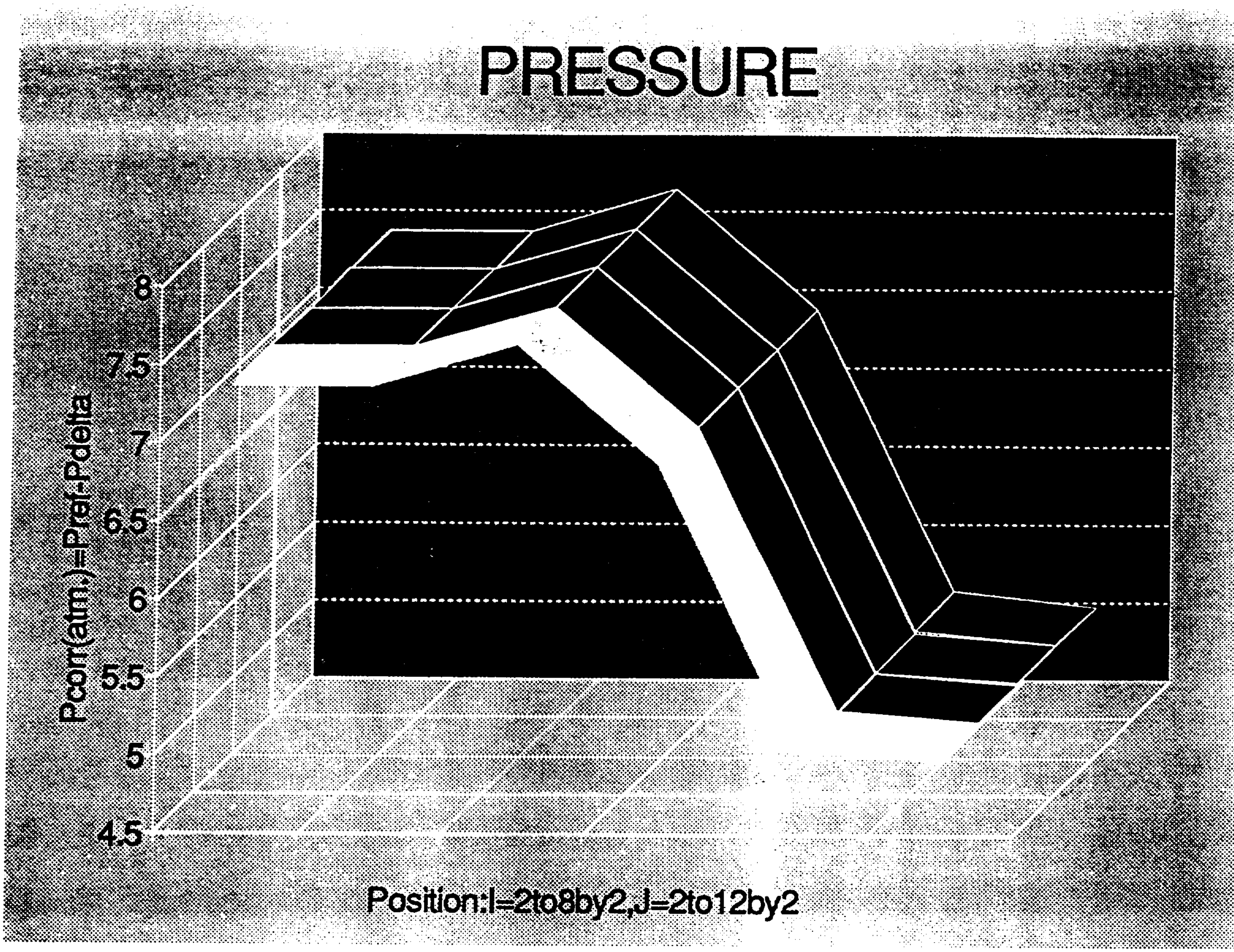

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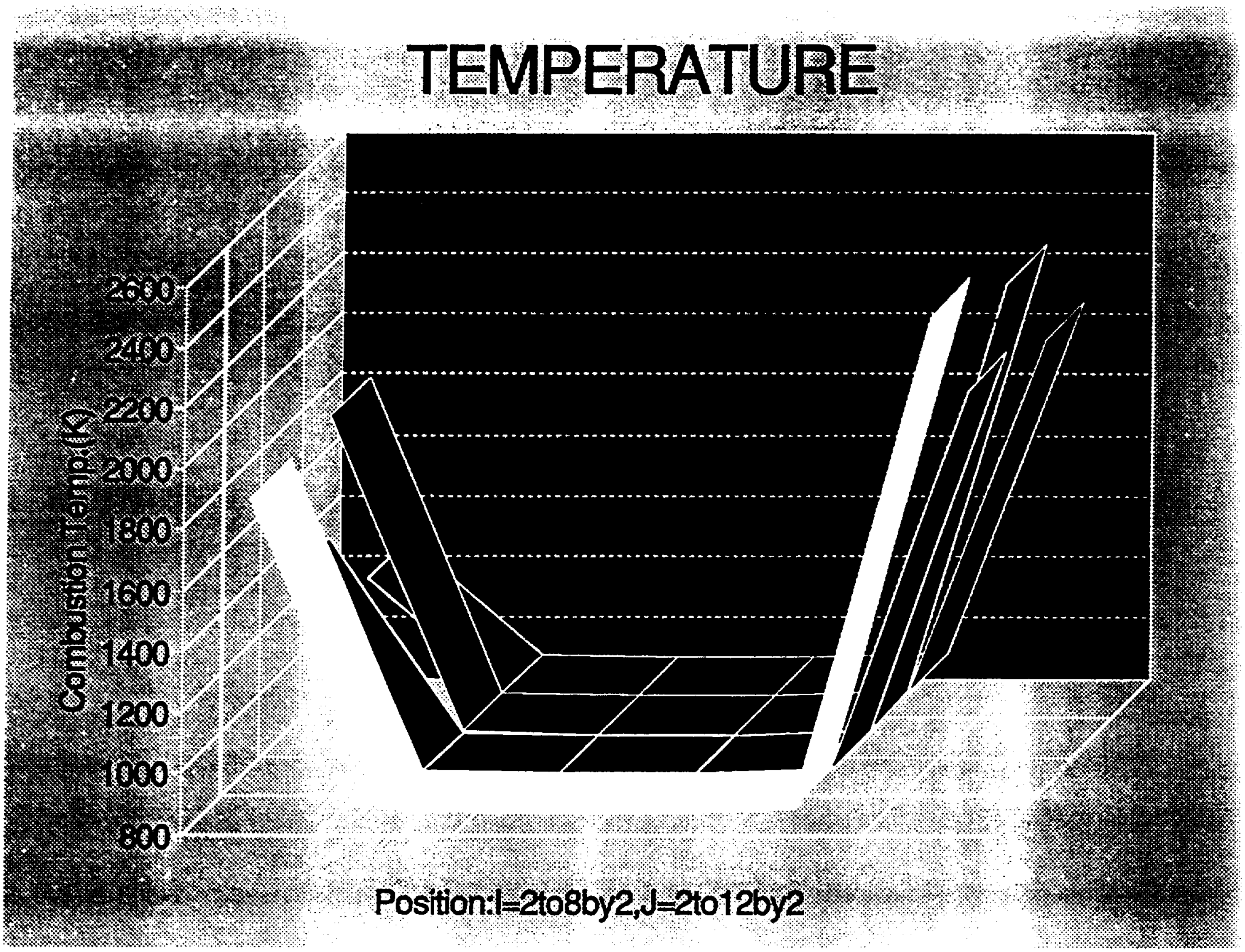

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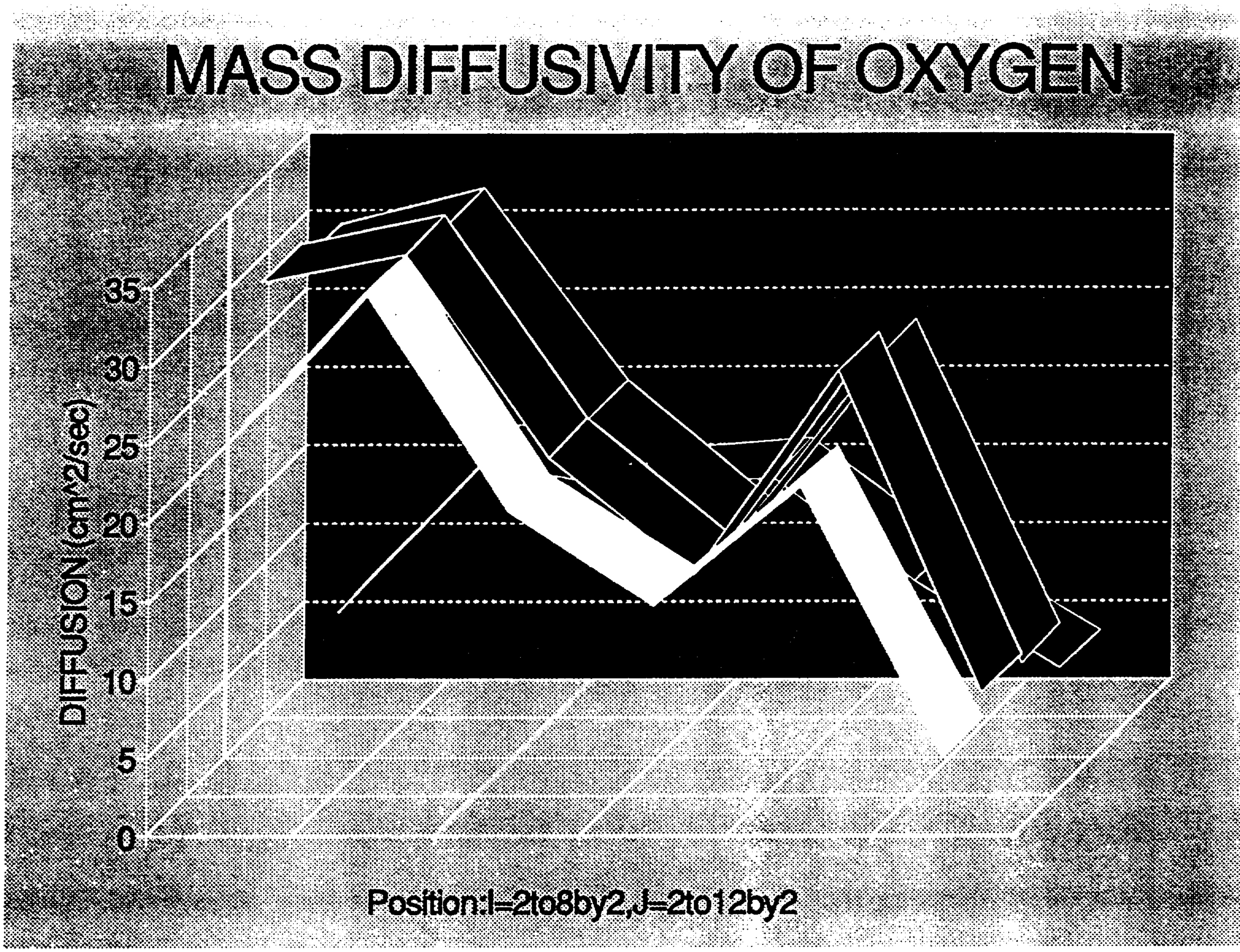
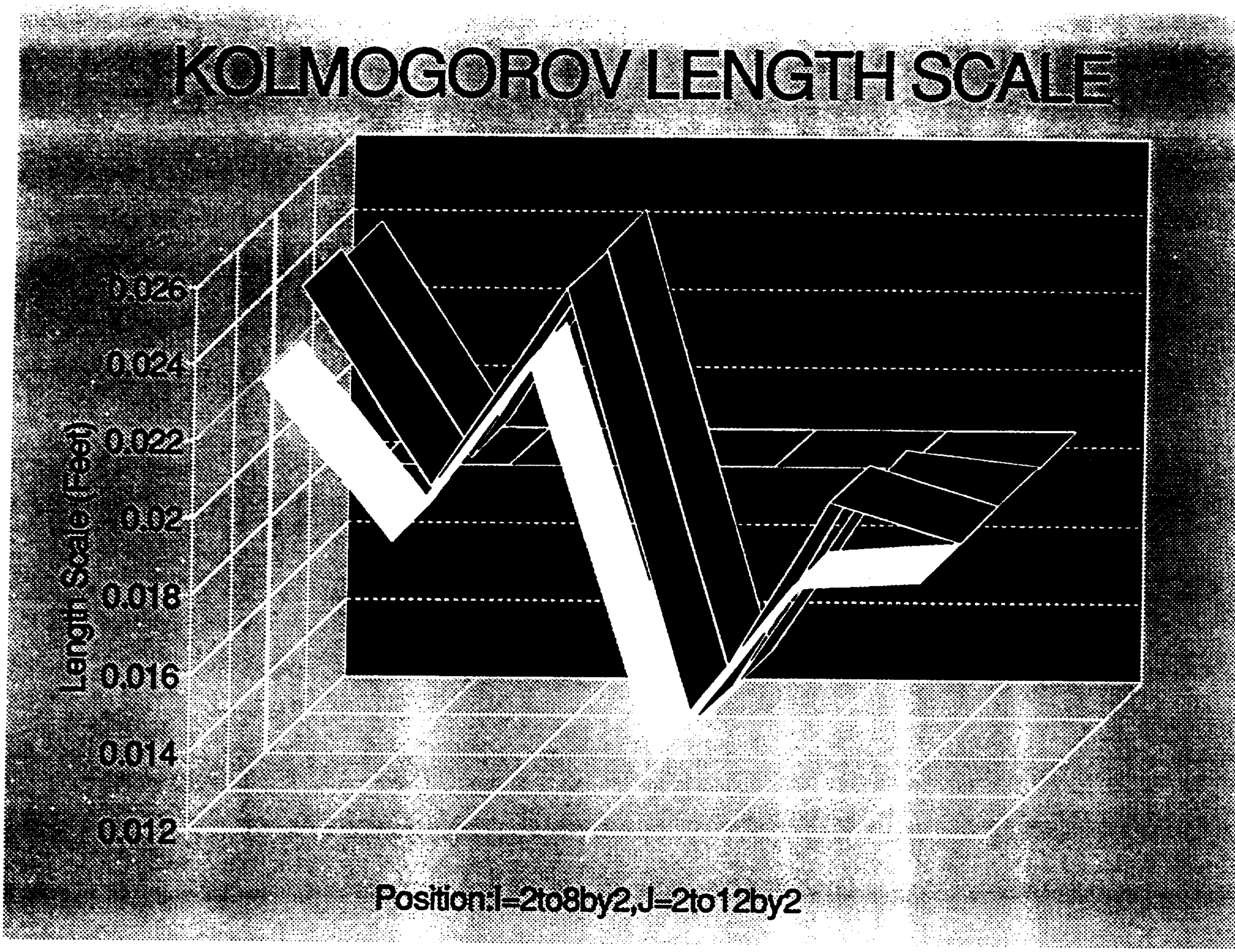
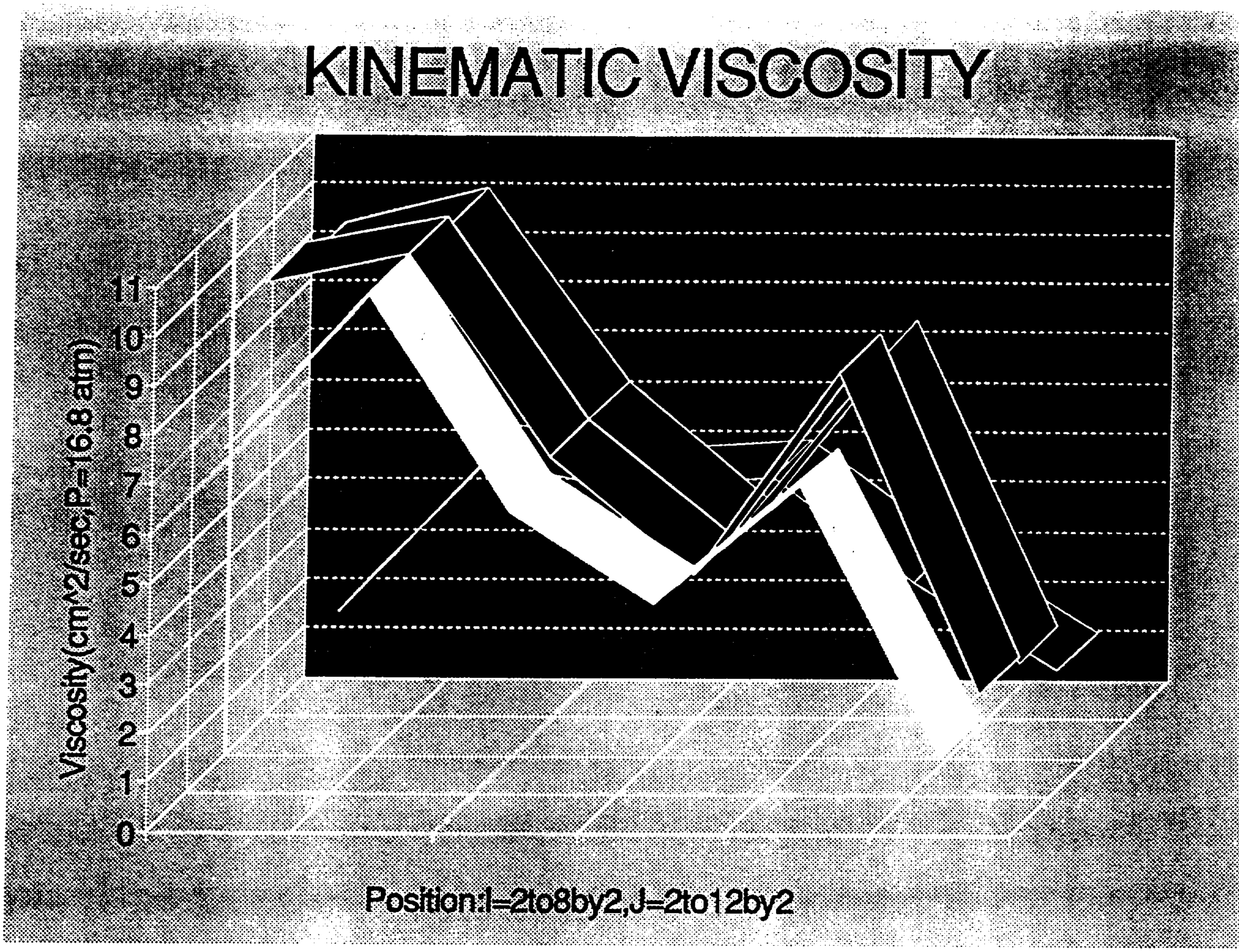



KOLMOGOROV LENGTH SCALE
Length Scale (Feet)
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
Position:I=2to8by2,J=2to12by2


KINEMATIC VISCOSITY
Viscosity(cm^2/sec,P=16.8 atm)
0
1
2
3
4
5
6
7
8
9
10
11
Position:I=2to8by2,J=2to12by2


MIXING TIME OF O2(tbar=.00375)
Mixing Time Constant(O2,sec)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
Position:I=2to8by2,J=2to12by2